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PB 151399-7

NBS

Technical Note No. 40 - 7

Boulder Laboratories

MEAN ELECTRON DENSITY VARIATIONS OF THE QUIET IONOSPHERE NO. 7 - SEPTEMBER 1959

BY J. W. WRIGHT, L. R. WESCOTT AND D. J. BROWN

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS

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April 1962

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ABSTRACT

The CRPL has initiated a program for large-scale computation of electron density profiles from ionospheric vertical soundings. Scaling is performed at field stations, permitting computation of hourly profiles at the Central Laboratory. These profiles are combined to form hourly mean quiet profiles for each station and month. The results of this program for the month of September are illustrated graphically. This report is the seventh of a series illustrating the electron density variations in the mean quiet ionosphere between latitudes 15°N and 50°N along the 75°W meridian.

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I. Introduction

Part of the basic responsibility of the Central Radio Propagation Laboratory is to gather ionospheric, solar, or other geophysical data necessary in the pursuit of research leading to improvements in radio communication and knowledge of the earth's upper atmosphere. The existing network of ionospheric vertical sounding stations is an important source of such data. Typically, the radio sounding data directly provide observations of peak electron densities (corresponding to "critical" frequencies foE, foF1, foF2), data on Sporadic E, and certain derived propagation data such as maximum usable frequencies or MUF factors (Smith, 1939).

In fact, the vertical sounding is potentially capable of providing the complete electron density profile of the underside of the ionosphere (i.e., below hmax F2) and of providing a basis for extrapolation to much greater altitudes. However, because a lengthy and difficult calculation is required, little of this work had been done until quite recently when techniques and computers have become available and the exigencies of the IGY and satellite programs have made it imperative.

In the course of its development of facilities for electron density profile calculations, the CRPL has succeeded in devising means by which basic data for this purpose may be scaled by the individual field stations, thereby decentralizing and simplifying the most onerous part of the work. Through its own station network and those of the U. S.

Army Signal Radio Propagation Agency, and through cooperation with closely associated stations in other countries, the CRPL has initiated an extensive systematic data reduction program, from which hourly electron density profiles are being computed for the following stations:

Puerto Rico (NBS, January 1959)
Grand Bahama Island (U. S. Army Signal Corps, February 1959)
Fort Monmouth, New Jersey (U.S. Army Signal Corps, Feb. 1959)
White Sands, New Mexico (U.S. Army Signal Corps, March 1959)
St. Johns, Newfoundland (Def. Res. Tel. Establ. Canada, June 1959)
Adak, Alaska (U.S. Army Signal Corps, June 1959)
Okinawa, Ryukus (U.S. Army Signal Corps, June 1959)
Thule, Greenland (U.S. Army Signal Corps, July 1959)
Huancayo, Peru (January 1960)
Talara, Peru (January 1960)
Baguio, Philippines (February 1960)

Affiliation and approximate date of initial participation in this program are given in parentheses.

The hourly electron density profiles are extensively used in the research programs of CRPL and are supplied directly to certain other agencies as part of various research and practical activities. However, in this comparatively early stage, broad dissemination of the computed data is a somewhat difficult problem.

In an attempt to make at least a summary of the results of the program widely and rapidly available, the CRPL has initiated the present series of reports. These provide graphical representations of the monthly mean quiet hourly electron densities from certain of the stations in the preceding list, from which a fairly clear picture of the local ionosphere morphology may be obtained.

These reports contain N(h) data for the stations at Newfoundland, Fort Monmouth, Grand Bahama Island, White Sands, and Puerto Rico. Pertinent facts concerning these stations are given in the following table:

Table 1

		Geomag. Coordinates		Geog. Coordinates	
	fH	Lat.	Dip		
St. Johns, Newf.	1.38 Mc/s	58.5°N	72°N	47°33'N	52°40'W
Ft. Monmouth, N.J.	1.46	51.7°N	71.5°N	40°15'N	74°01'W
White Sands, N.M.	1.30	41.2°N	60°N	32°24'N	106°52'W
Grand Bahama Island	1.30	37.9°N	59.5°N	26°40'N	78°22'W
Puerto Rico	1.15	30°N	51.5°N	18°30'N	67°12'W

II. Description of Basic Data

True heights of reflection of radio waves are calculated from the observed or "virtual" heights by the method of Budden (1954); this method need not be described here, but it should be pointed out that full correction for geomagnetic field effects is made and that the usual restrictions to monotonic profiles apply.

Tabulations of the mean electron density data at 10 km intervals and certain related quantities are the bases for the graphs and charts. A sample for the Puerto Rico September data is given on Page 11. The table on the following page identifies the quantities appearing on the tabulation.

Quantity	Units	Remarks
Average Electron Density (N)	$x10^{3}$ = electron/cm^{3} (10^{-5} on maps)	Body of table; given at each 10 km of height from the lowest hmin to 950 km.
NMAX	$x10^{3}$ = electron/cm^{3} (10^{-5} on maps)	The mean value of Nmax.
COUNT		Count of the number of profiles entering the mean.
HMIN	Kilometers	The average height of zero or very low electron density, obtained by linear extrapolation of the electron density of the individual profiles.
HMAX	Kilometers	The average height of maximum electron density, determined by fitting a parabola to the upper portion of the individual profiles.
SCAT	Kilometers	One half of the half-thickness of the parabola best fitting the upper portion of the F-region profile. Approximates the scale height near the true HMAX.
SHMAX	$x10^{10}$ = electrons/cm^{2} column (10^{-12} on maps)	Obtained by averaging the integration of the individual profiles between the limits HMIN and HMAX.
SHINF	$x10^{-10}$ = electrons/cm^{2} column (10^{-13} on maps)	The average total number of electrons in a column to infinity obtained by extrapolation of observed profiles into the region above HMAX. (See text.)

The following particular features of the tabulated data should be noted:

A. Averaging process. Each hour of each day is identified with its magnetic character figure, Kp. For each hour, those days for which Kp is less than 4+ are included in the "quiet" average. The other days are similarly combined to form a "disturbed" average; however, this rarely has physical significance because the number of disturbed periods is usually small and the behavior of the ionosphere during disturbed hours is not consistent. Thus, graphs for these latter averages are not presented here.

B. Determination of hmax. The nature of the "true height" process is such that no direct measure of hmax F2 is obtained, the virtual height at Nmax being immeasurable. A useful procedure is to fit the portion near hmax F2 with a suitable curve and to determine hmax from this curve. A parabola is quite satisfactory for this purpose; it is fitted to two of the highest true heights and the measured value of Nmax (foF2).

C. Extrapolation of profiles above hmax. Before averaging, the individual profiles are extrapolated above hmax by a Chapman distribution of 100 km scale height. This assumed model seems to agree well with the few published measurements dealing with the profile of the F region above hmax (Wright, 1960). Extrapolation is necessary in order to calculate homogeneous averages near hmax, and the average profiles are, in fact, given to 950 km.

D. Integrated electron densities. The total number of electrons in a unit column of the ionosphere between the effective bottom (hmin) and hmax is called Shmax; it is obtained by numerical integration of the observed profiles between these limits. An estimate of the total electron content to infinity, based upon the Chapman model, is called Shinf. It is obtained by adding to Shmax the quantity $N_A = 2.82\,HNmax$ where H is an (assumed constant) scale height for the region above hmax. Current evidence (Wright, 1960) indicates H = 100 km, is an acceptable choice.

III. Description of Graphical Representation

The relative smoothness of mean quiet ionosphere data lends itself to various kinds of graphical presentation which offer convenient aids to the visualization of the height, geographic, and temporal variability of the ionosphere. Included here are three such graphical forms prepared from the tabulations described in Section II.

A. Vertical cross sections of the ionosphere along the 75°W meridian. Pages 12 through 35 give, for each hour, a vertical cross section of the mean quiet ionosphere along a meridian section, nominally the 75°W geographic meridian, for the month of September 1959. Contours are parametric in "plasma" frequency (f_N) related to electron density N by

$$12{,}400\ f_N^2\ (\mathrm{Mc/s}) = N(\mathrm{electrons/cm^3}).$$

The height of maximum electron density is represented by a dashed line. Note that the vertical scale is expanded about 5.5 times.

With the exception of White Sands, each of these stations is reasonably close to the 75°W meridian (see Table 1). There is the possibility that some of the anomalies imposed by White Sands on these contours are the result of the well-known longitudinal asymmetry of the ionosphere.

B. Local time vs. Latitude Maps. Another form of presentation, useful for indicating the two-dimensional geographic variations of the ionosphere, is that illustrated by the maps of pages 36 through 45. Here, for fixed levels in the ionosphere (150, 200, 250, 300, 350, 400 km), contours of electron density are drawn in the latitude vs. local time plane. To the extent to which longitude anomalies are negligible, these maps give also the longitude vs. latitude distribution of electron densities at the indicated heights when it is noon over the 75°W meridian. Similar maps for the peak density, Nmax; its height, hmax; its characteristic thickness, Scat; the total electron content to Nmax, Shmax; and the estimated total electron content, Shinf, are also shown.

C. Electron density vs. time curves (N(t) curves). The mean quiet diurnal variation of electron density between 150 and 400 km heights above the sounding stations is illustrated by these curves. Dashed lines are used wherever the electron density at any height falls below the peak density (i.e. when the height hmax F2 falls below the height for the curve in question.) Such electron densities are the result of the extrapolations by the Chapman model discussed in Section II C.

IV. Discussion and Applications of the Data

Mean quiet electron density data over wide geographic areas are essential for application to numerous problems of both practical and scientific interest. For example, the assessment of the radio refraction errors and Faraday rotation effects in satellite tracking requires a knowledge of the electron density profile in the direction of the satellite or an estimate of the electron density at the satellite itself. Alternatively these properties of the ionosphere, or estimates of the total electron content in a column, may be measured by observations from rockets and satellites, or from radar moon-echoes, and compared with ground-based observations of the kind shown here.

Frequently it will be necessary to use instantaneous density data because of the considerable variability of the ionosphere about the quiet mean. In such cases, the mean data are of value as a "reference level" in the design of the experiment; for example, in the choice of radio frequencies, satellite heights, antennas, etc.

Since electron density data represent virtually our only source of continuous, widespread data on the earth's upper atmosphere, such data also are essential to geophysical problems involving the electrical, neutral, and magnetic properties of the atmosphere.

For example, data on the vertical cross sections may be compared with theoretical expectations for the meridional height dependence of the quiet ionosphere. Several workers (Hirono, 1955; Martyn 1956) have investigated the equilibrium height (of hmax) for an ionosphere controlled by diffusion, height-varying electron loss rate, and uniform (or zero) vertical electron drift. The results are qualitatively in agreement with these observations in predicting a rise of hmax towards the equator in daytime and a reversal of this tendency at night.

The N(t) curves are perhaps the most physically significant representation of electron density data. The strong solar control at all levels and the important perturbations of this solar control in the upper F region may be easily seen.

Acknowledgments

We are indebted to Mr. A. H. Shapley for guidance in the initiation of this work, and to Dr. H. H. Howe for the development of the computer programs upon which the whole system heavily depends. This series of reports results from the combined efforts of the NBS Electron Density Profile Group, including at various times L. R. Wescott, L. Hayden, D. J. Brown, F. J. Burmont, I. Ford, N. Moore, M. Durham, G. Lira, under the direct supervision of G. H. Stonehocker. The cooperation of the U. S. Army Signal Radio Propagation Agency is gratefully acknowledged.

References

Budden, K. G., "A method for determining the variation of electron density with height (N(z) curves) from curves of equivalent height against frequency (h'(f) curves). Proc. Cambridge Conf. on the Physics of the Ionosphere, pp 332-339, September 1954, Pub. by the Physical Society (1955).

Martyn, D. F., "Processes controlling ionization distribution in the ionosphere," Aust. J. Phys. 9, pp 161-165, March 1956.

Hirono, M., "Effect of gravity and pressure gradient on vertical drift in the F2 region," Rpt. on Iono. Res. in Japan, 9, No. 2, pp 95-104, (1955).

Smith, N., "The relation of Radio Skywave Transmission to Ionosphere Measurements," Proc. IRE, 27, No. 5, pp 332-347, (1939).

Wright, J. W. "A model of the F region above hmax F2," Journal of Geophysical Research, 65, 185-191, January 1960.

AVERAGE ELECTRO DENSITY — KP BELOW 4.5

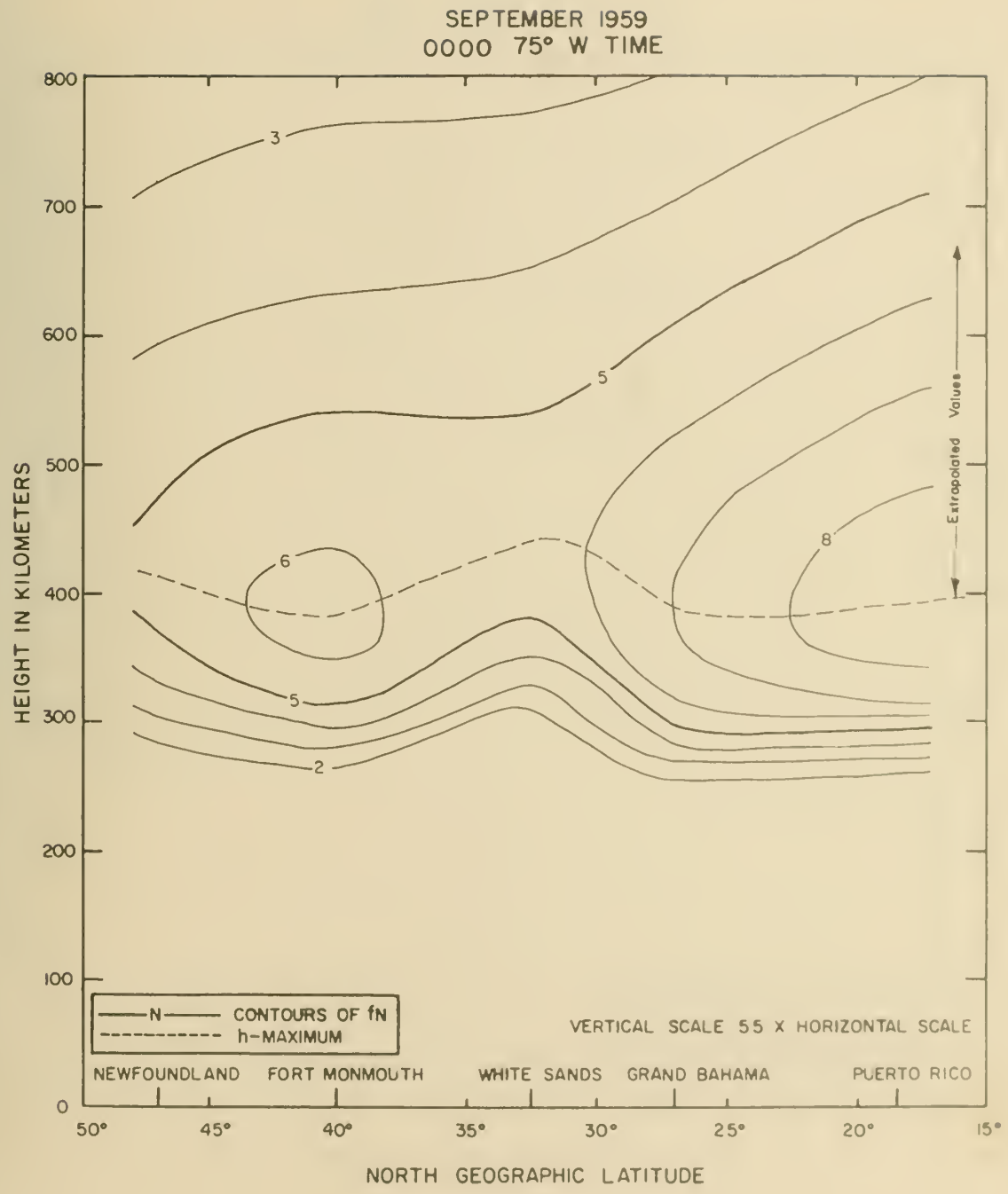
PUERTO RICO — 60 M — SEPT 1959

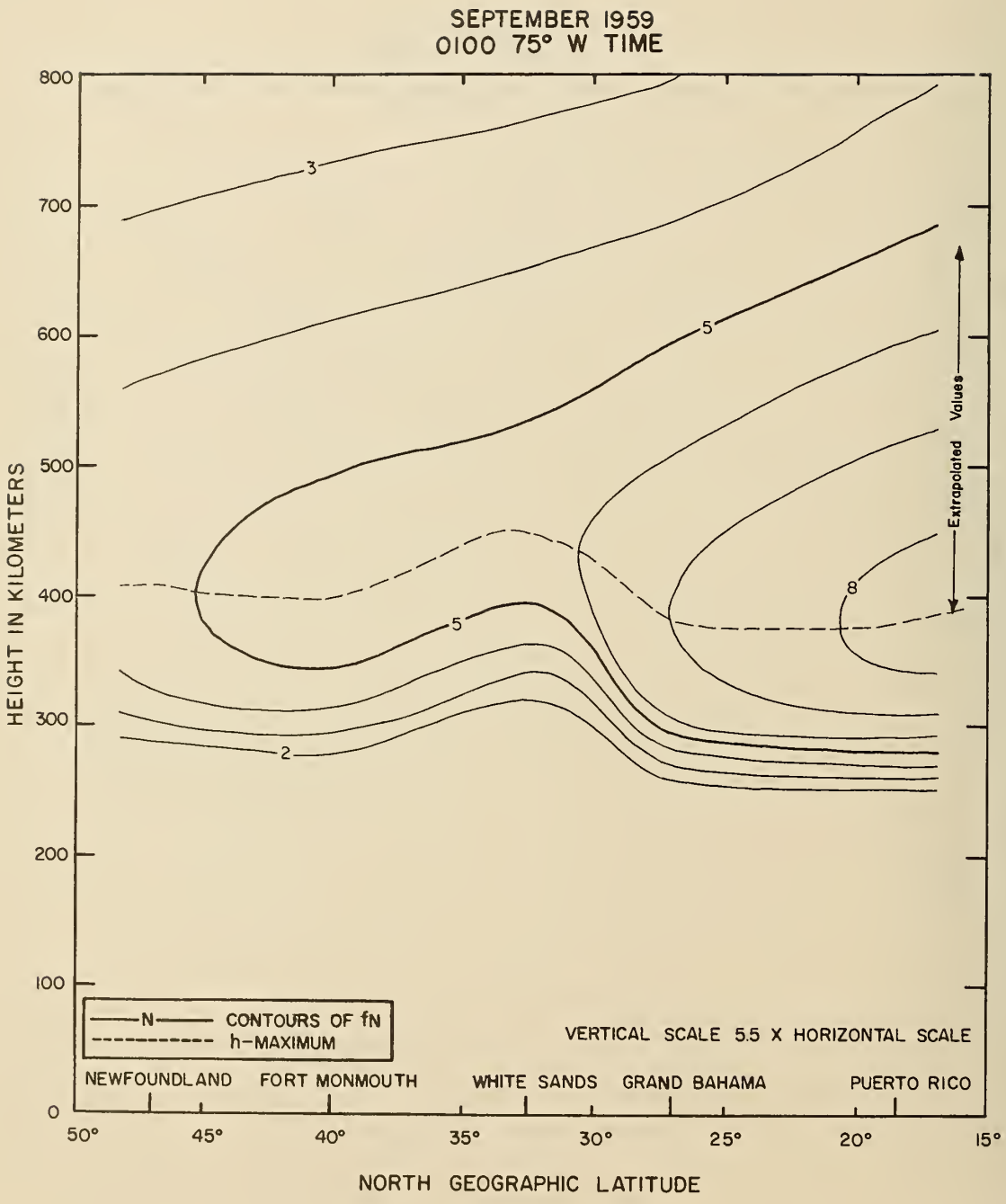
TIME	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
COUNT	19	21	25	24	25	22	23	17	21	22	19	17
HMIN	262	55	241	229	234	265	276	121	113	113	113	112
NMAX	956	893	756	564	435	375	393	881	1214	1534	1758	1845
HMAX	379	364	19	355	383	401	390	295	315	331	341	358
HMAX	650	570	508	430	37	314	291	66	1176	15	1496	2169
SHINF	3346	3088	2649	2042	1601	1373	1400	3148	4631	59.0	6855	7374
KM												
950	90.5	78.	62.5	47.9	41.7	40.5	39.7	55.	84.7	115	138	157
900	118	100	80.	61.4	53.5	51.3	51.2	7	104	148	176	201
850	149	124	103	78.3	66.5	64.	65.5	81.	131	189	226	258
800	190	165	13	101	8	81.	83.8	117	179	243	290	331
750	243	211	168	129	11	109	107	150	229	310	371	423
700	310	269	215	164	14	138	136	19	292	396	473	539
650	394	341	273	209	181	174	172	247	373	505	602	685
600	492	429	344	263	22	219	215	311	473	639	762	864
550	609	533	430	328	279	26	264	391	595	801	954	1078
540	634	556	449	342	30	271	274	411	622	836	997	1126
530	659	578	467	356	302	280	284	430	650	873	1040	1175
520	685	601	487	370	313	290	295	450	679	911	1085	1220
510	710	625	507	385	325	299	305	470	709	949	1130	1270
500	736	648	527	400	336	307	315	491	739	985	1176	1319
490	761	672	547	415	347	315	325	513	771	1029	1223	1369
480	786	695	567	430	358	323	334	535	802	1069	1271	1419
470	810	718	587	445	368	329	343	558	834	1110	1318	1469
460	833	740	607	459	378	335	351	581	867	1151	1365	1518
450	855	762	626	473	388	340	359	604	900	1191	1412	1565
440	875	782	645	487	396	344	366	627	932	1231	1458	1611
430	893	801	661	499	404	346	371	651	964	1270	1503	1655
420	909	818	680	511	410	346	375	675	996	1308	1546	1696
410	921	833	696	522	415	344	376	698	1027	1345	1587	1733
400	928	844	710	531	418	340	375	721	1057	1379	1624	1765
390	930	851	721	537	419	333	371	744	1085	1411	1658	1793
380	926	853	729	540	417	324	364	766	111	1436	1687	1814
370	910	847	733	541	411	311	352	786	1136	1464	1711	1827
360	883	834	733	541	403	296	335	805	1156	1485	1729	1832
350	840	813	726	534	390	278	311	823	1174	1500	1740	1824
340	783	780	711	522	373	258	284	838	1187	1509	1741	1801
330	709	739	688	505	351	235	253	851	1195	1511	1733	1760
320	619	694	654	481	326	209	219	860	1196	1504	1716	1700
310	513	641	607	451	296	181	180	865	1189	1483	1684	1620
300	403	578	544	416	261	151	144	866	1174	1446	1584	1521
290	291	507	464	376	224	129	112	860	1144	1386	1493	1406
280	189	433	379	331	187	106	87	846	1101	1304	1383	1279
270	108	355	293	283	154	91	74	817	1041	1207	1260	1149
260	51.5	283	218	240	131	80.5	71.6	770	965	1083	1126	1022
250	31.	224	171	206	116	73.	69.	711	874	949	985	901
240	20.	179	139	179	104	68.	68.	644	771	835	850	791
230	14.	146	118	158	96.	64.	69.0	570	662	730	727	695
220		122	104	144	91.	62.	71.	490	560	634	619	612
210		104	93.	134	88.	61.	76.	407	470	546	529	539
200				128	85			327	393	463	456	478
190								253	325	390	397	428
180								189	268	331	345	384
170								135	220	284	307	352
160								94.	180	249	280	332
150								78.	155	221	258	297
140								71.	134	200	240	254
130								67.	121	189	219	222
120								64.	115	178	208	200
110								61.	114	176	206	196
100								59.	113	175	205	195

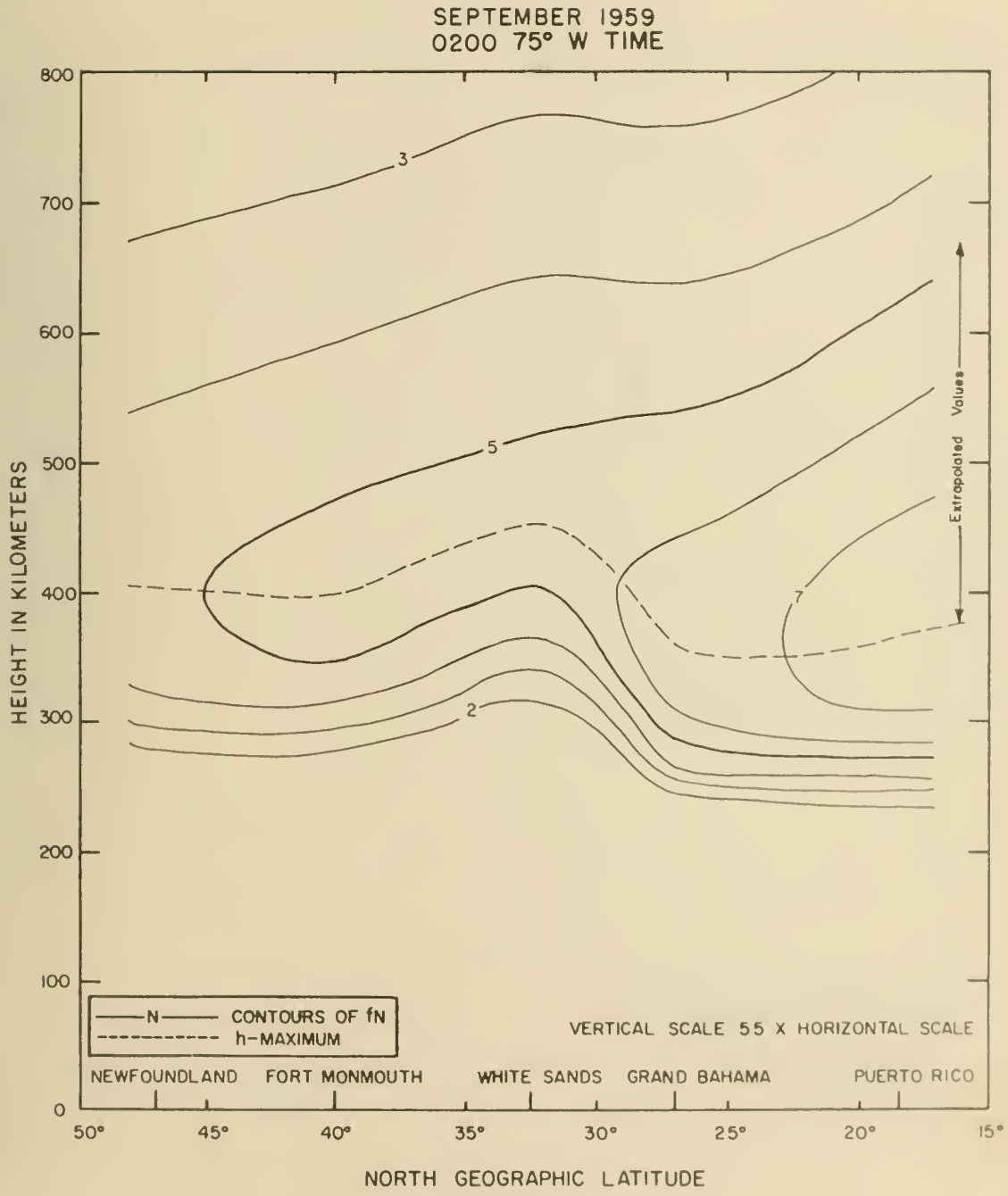
AVERAGE ELECTRON DENSITY — KP BELOW 4.5

PUERTO RICO — 60 M — SEPT 1959

TIME	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
COUNT	20	19	21	22	20	15	9	19	22	21	22	18
HMIN	113	112	113	113	113	113	199	224	235	258	274	277
NMAX	2013	2077	2168	2134	1975	1816	1601	1355	1133	1094	976	1022
HMAX	368	372	374	376	367	354	365	378	400	400	407	393
SHMAX	2380	2470	2521	2508	2218	1902	1460	1220	1017	869	724	698
SHINF	8057	8330	8636	8529	7790	7026	5976	5044	4212	3957	3478	3481
KM												
950	180	190	201	199	176	153	141	128	119	115	106	104
900	231	244	257	255	226	196	181	164	153	147	135	134
850	296	312	330	327	290	251	232	211	195	189	173	171
800	379	400	423	418	371	322	297	270	250	241	222	219
750	485	511	540	534	475	412	379	344	319	308	283	279
700	618	651	688	681	605	525	484	439	406	391	359	355
650	784	826	872	863	768	668	614	556	512	494	453	449
600	987	1039	1097	1084	967	843	774	698	640	618	565	562
550	1227	1290	1361	1344	1202	1052	964	865	786	759	692	692
540	1279	1344	1418	1400	1253	1097	1005	901	817	789	718	719
530	1332	1399	1476	1457	1305	1144	1046	937	848	818	744	746
520	1386	1454	1534	1514	1358	1192	1089	974	878	848	770	774
510	1440	1510	1593	1572	1411	1240	1132	1011	908	877	796	801
500	1494	1566	1652	1629	1464	1289	1176	1048	938	906	821	828
490	1549	1622	1710	1687	1518	1338	1219	1084	967	934	845	856
480	1603	1678	1768	1743	1571	1388	1262	1120	995	961	868	880
470	1656	1732	1825	1799	1623	1437	1305	1155	1022	987	889	904
460	1708	1785	1880	1852	1674	1485	1347	1189	1046	1010	909	927
450	1758	1835	1934	1903	1723	1533	1386	1221	1068	1032	926	948
440	1806	1883	1982	1950	1770	1579	1426	1250	1087	1051	940	966
430	1850	1926	2027	1994	1813	1623	1463	1277	1103	1066	950	982
420	1890	1966	2067	2032	1853	1664	1496	1301	1114	1078	956	994
410	1925	2000	2101	2065	1888	1701	1526	1321	1121	1084	955	1001
400	1955	2027	2129	2090	1917	1735	1551	1336	1121	1084	946	1001
390	1978	2047	2148	2107	1935	1763	1572	1345	1112	1073	925	991
380	1993	2059	2157	2114	1944	1786	1586	1348	1092	1048	890	968
370	1998	2060	2153	2110	1939	1802	1593	1341	1059	1007	841	930
360	1992	2046	2131	2091	1952	1810	1590	1321	1011	950	776	873
350	1969	2012	2085	2053	1929	1807	1573	1286	948	877	696	799
340	1924	1954	2014	1992	1886	1789	1539	1235	871	789	602	706
330	1852	1872	1914	1905	1818	1751	1487	1168	783	689	501	592
320	1758	1768	1794	1794	1727	1691	1417	1084	688	577	397	469
310	1647	1646	1655	1665	1613	1606	1328	984	584	459	292	350
300	1522	1507	1503	1520	1484	1506	1223	867	480	337	200	243
290	1386	1362	1345	1369	1347	1388	1098	738	376	228	126	158
280	1239	1210	1185	1211	1194	1253	958	605	278	137	72.7	97.8
270	1091	1058	1034	1086	1140	1109	801	463	192	70.9	37.5	52.8
260	953	926	905	906	905	954	624	318	119	28.1	19.2	23.5
250	833	811	776	776	772	799	422	196	67.1	11.0	9.1	7.9
240	729	714	680	671	658	659	287	106	36.1	3.1	3.1	.2
230	646	634	601	587	573	533	149	48.0	17.1	.2	1.8	
220	577	569	536	520	488	476	80.7	20.8	8.2	.8		
210	519	512	483	466	422	344	40.4	7.7	4.3			
200	468	463	435	416	369	279	18.4	1.1	.8			
190	422	419	394	373	324	229	28.6					
180	379	380	357	333	285	191	23.					
170	340	345	321	296	249	162	19.8					
160	302	306	287	262	218	139	17.1					
150	266	271	256	231	190	123	15.1					
140	234	239	222	206	169	112	13.9					
130	212	216	204	190	157	104	12.8					
120	170	179	164	165	137	91.2	10.8					
110	8.7	10.7	10.3	13.4	8.6	10.7						


SEPTEMBER 1959
0000 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
5
6
8
5
2
Extrapolated Values
—N— CONTOURS OF fN
---------- h-MAXIMUM
VERTICAL SCALE 55 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


SEPTEMBER 1959
0100 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
5
5
8
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE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0200 75° W TIME
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700
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400
300
200
100
0
HEIGHT IN KILOMETERS
3
5
7
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 55 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
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20°
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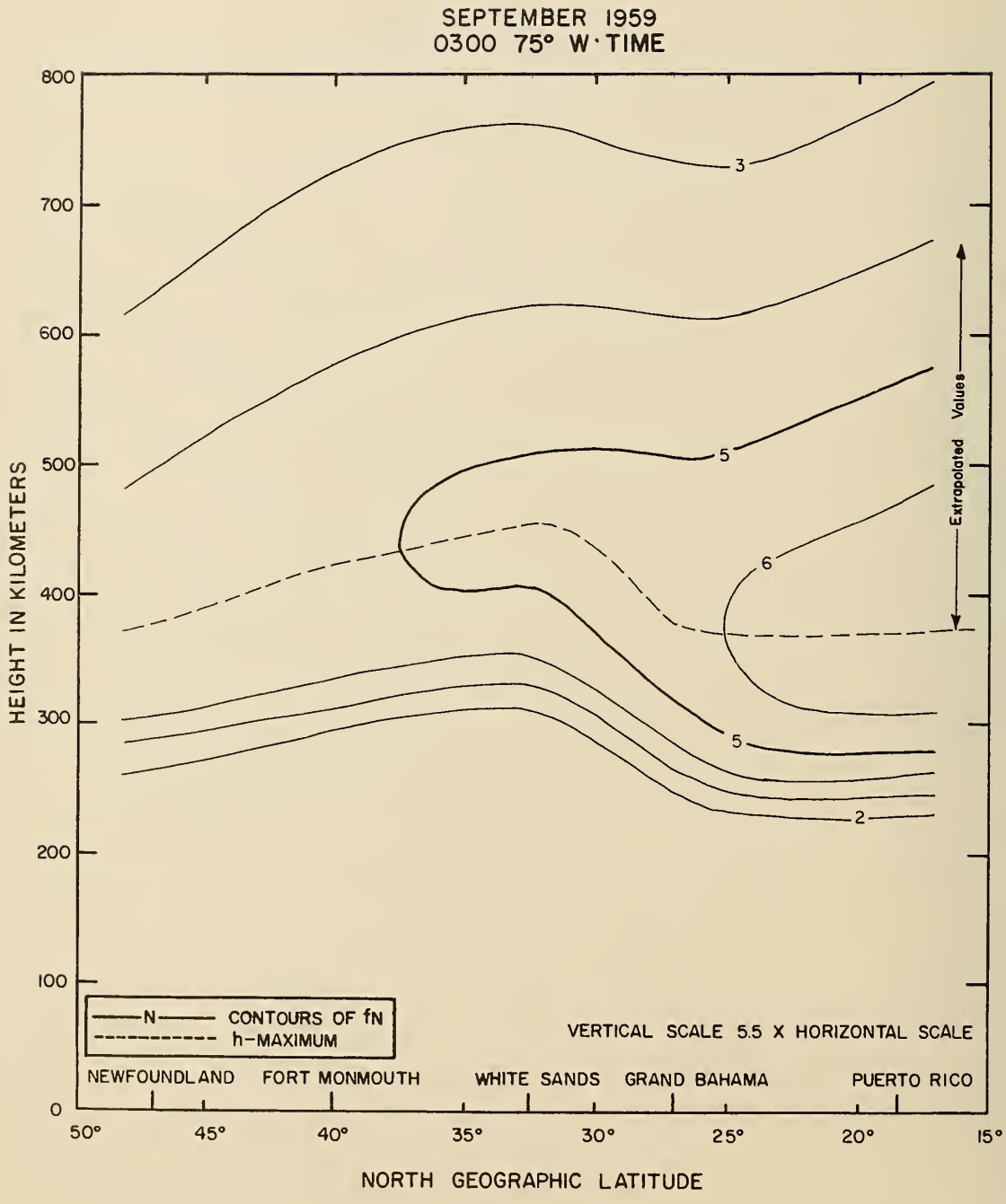
NORTH GEOGRAPHIC LATITUDE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0300 75° W TIME
HEIGHT IN KILOMETERS
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700
600
500
400
300
200
100
0
3
5
6
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
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20°
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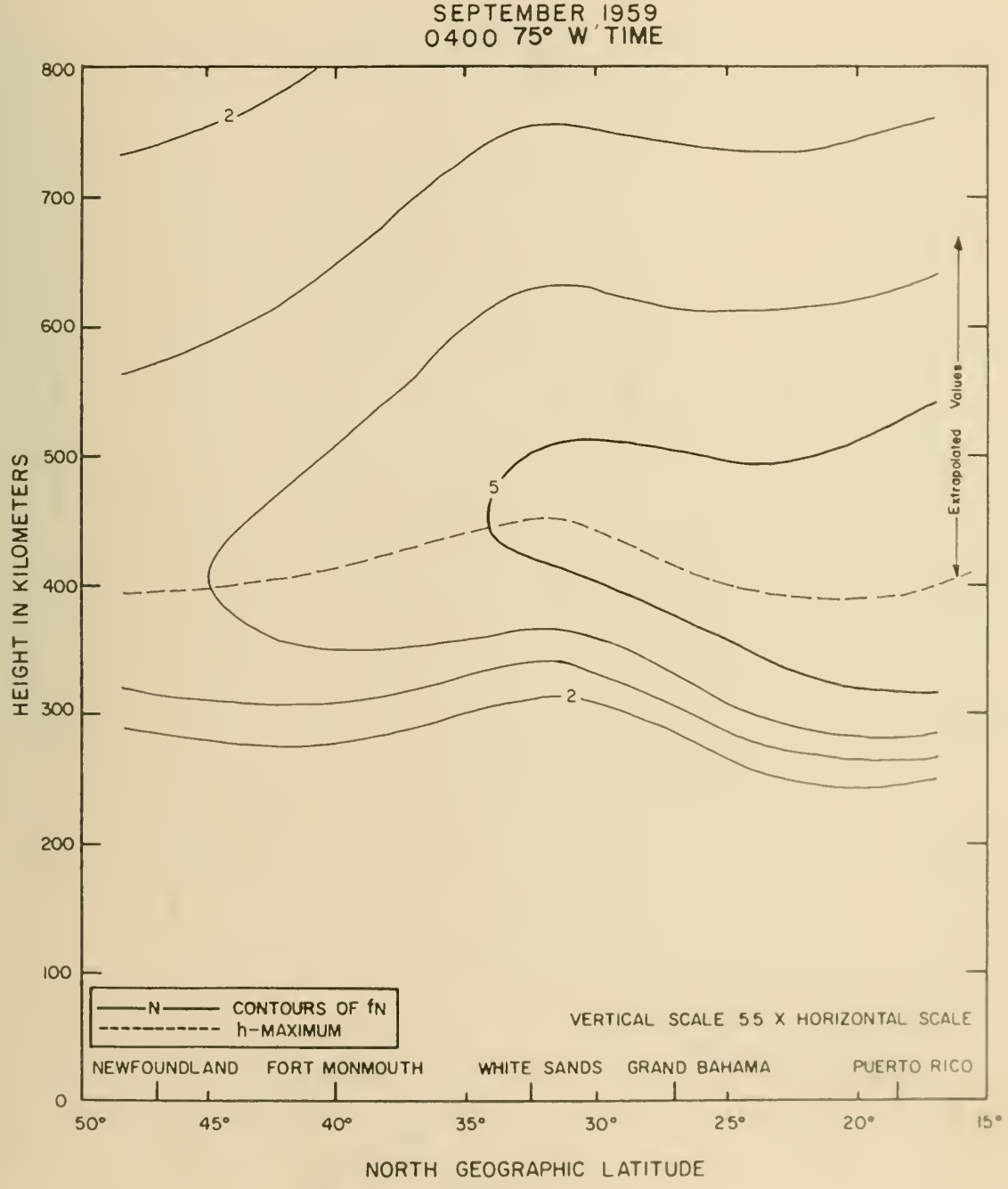
NORTH GEOGRAPHIC LATITUDE


SEPTEMBER 1959
0400 75° W TIME
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700
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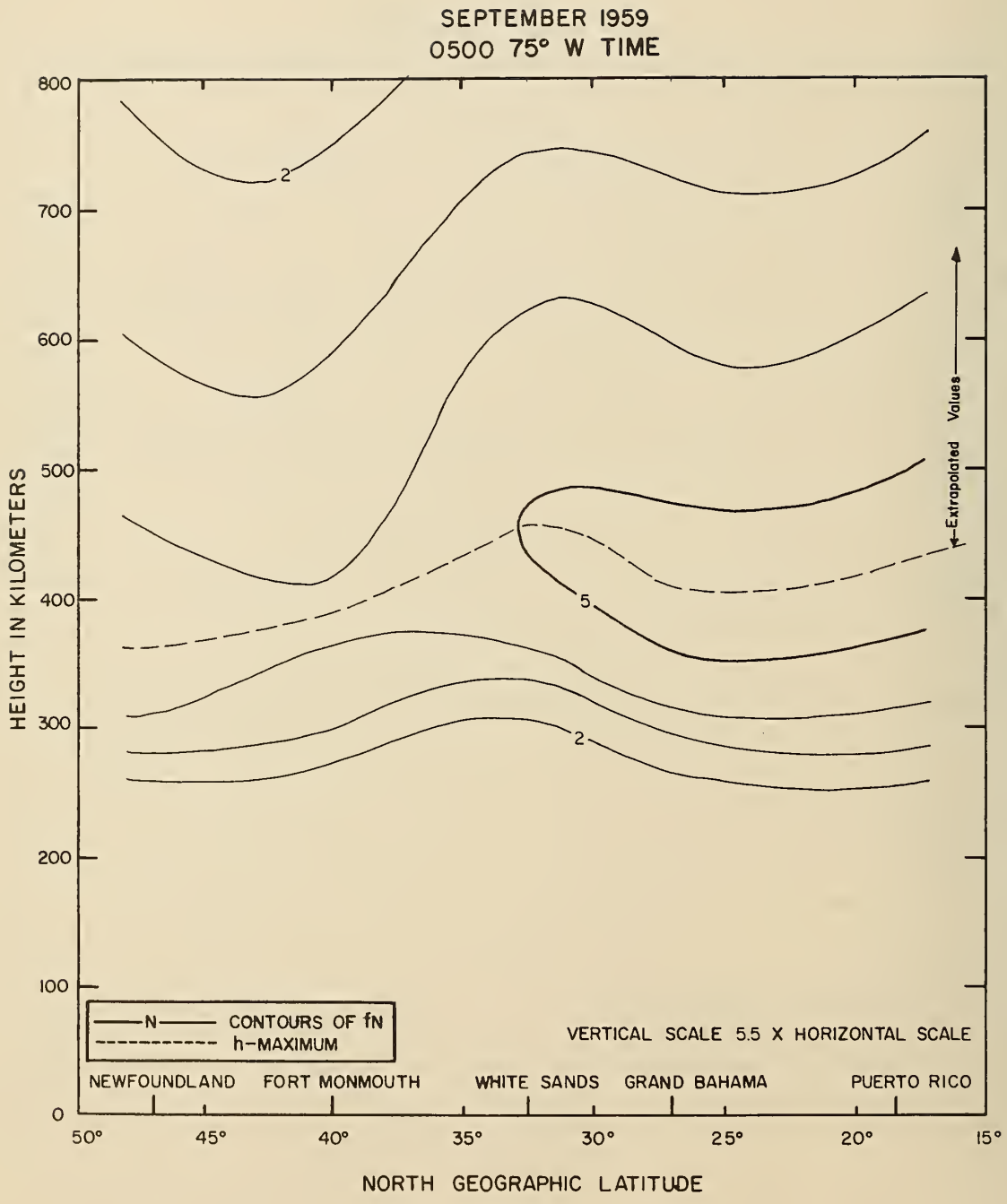
500
400
300
200
100
0
HEIGHT IN KILOMETERS
2
5
2
Extrapolated Values
—N— CONTOURS OF fN
---------- h-MAXIMUM
VERTICAL SCALE 55 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


SEPTEMBER 1959
0500 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
2
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
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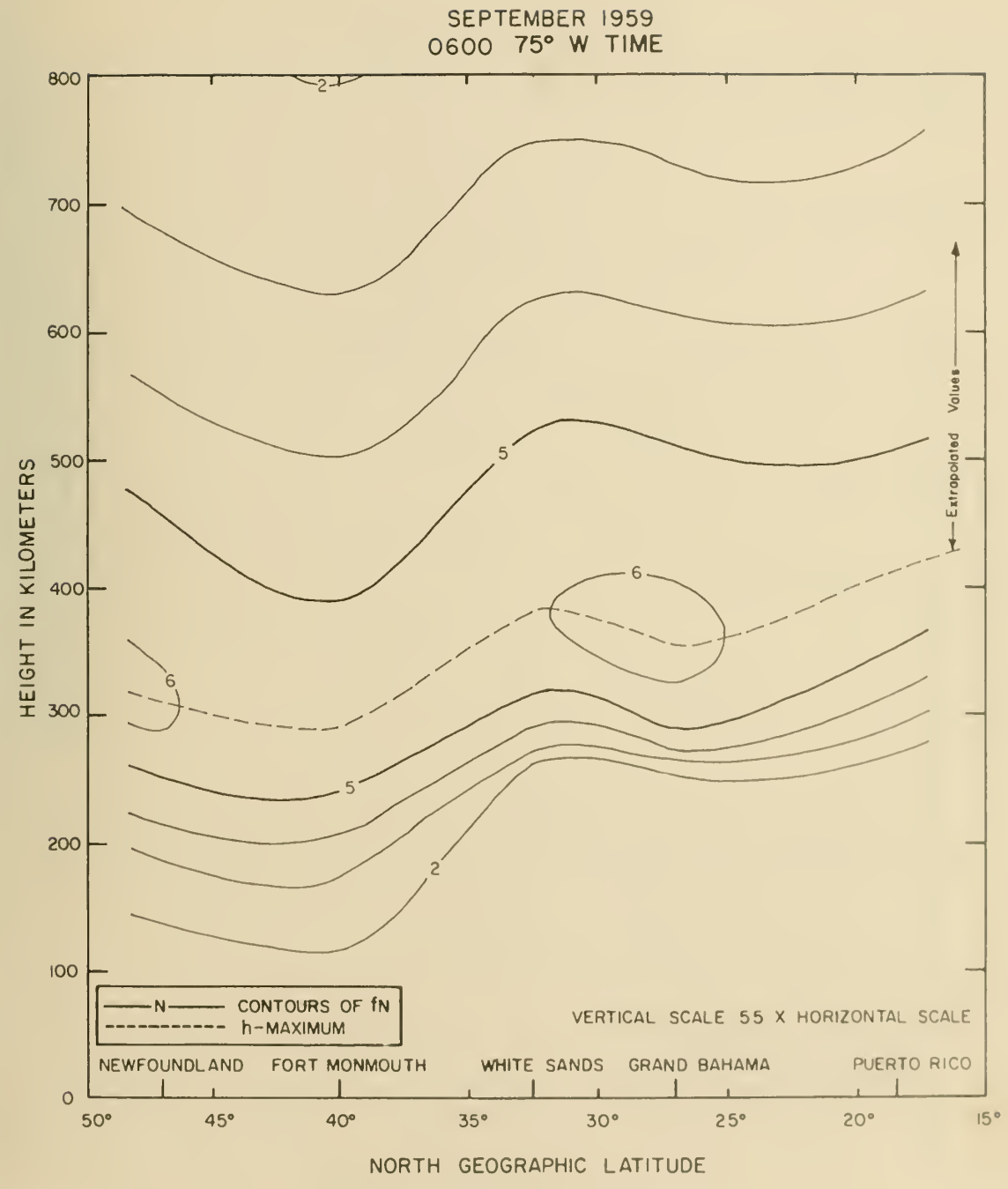
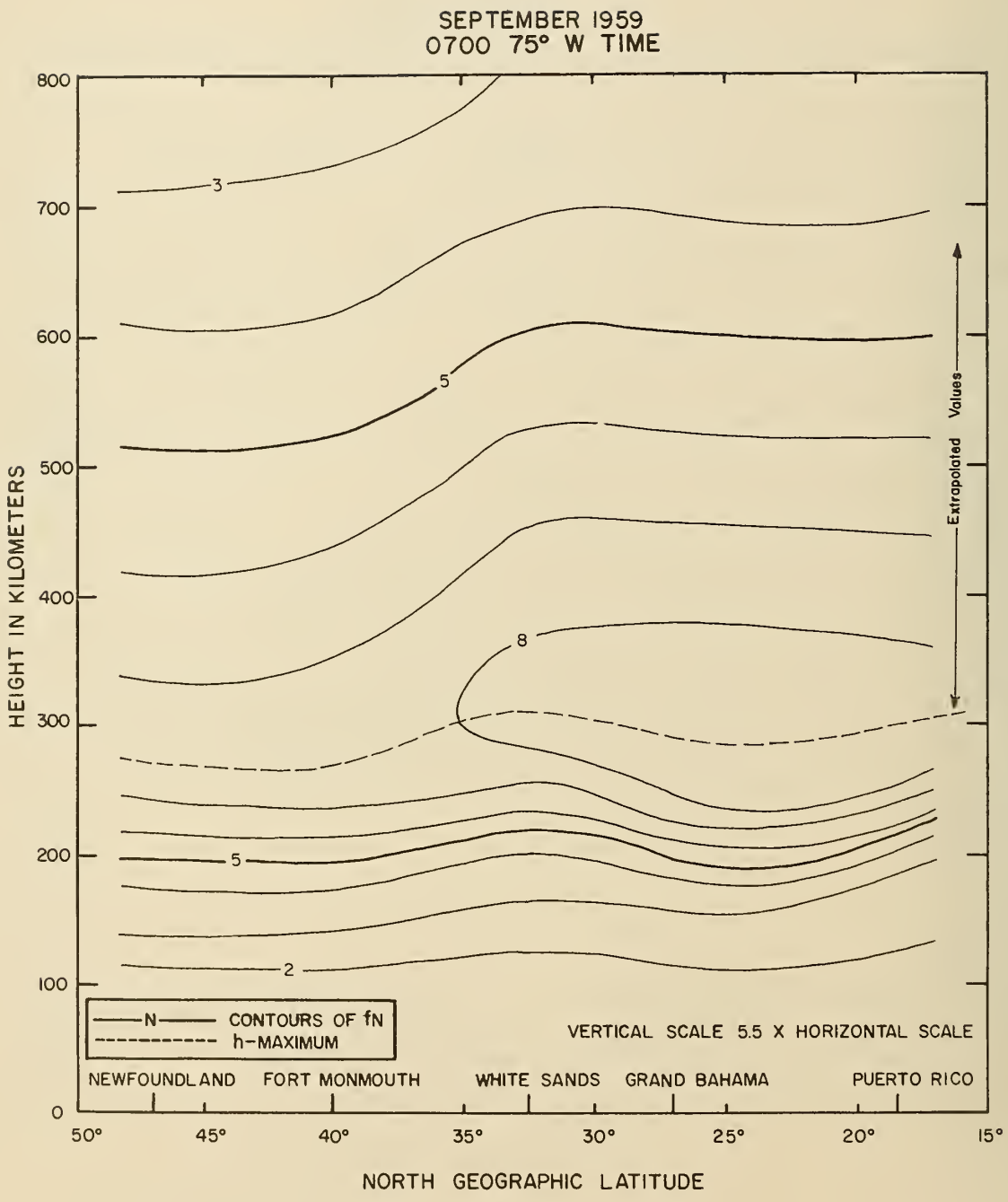
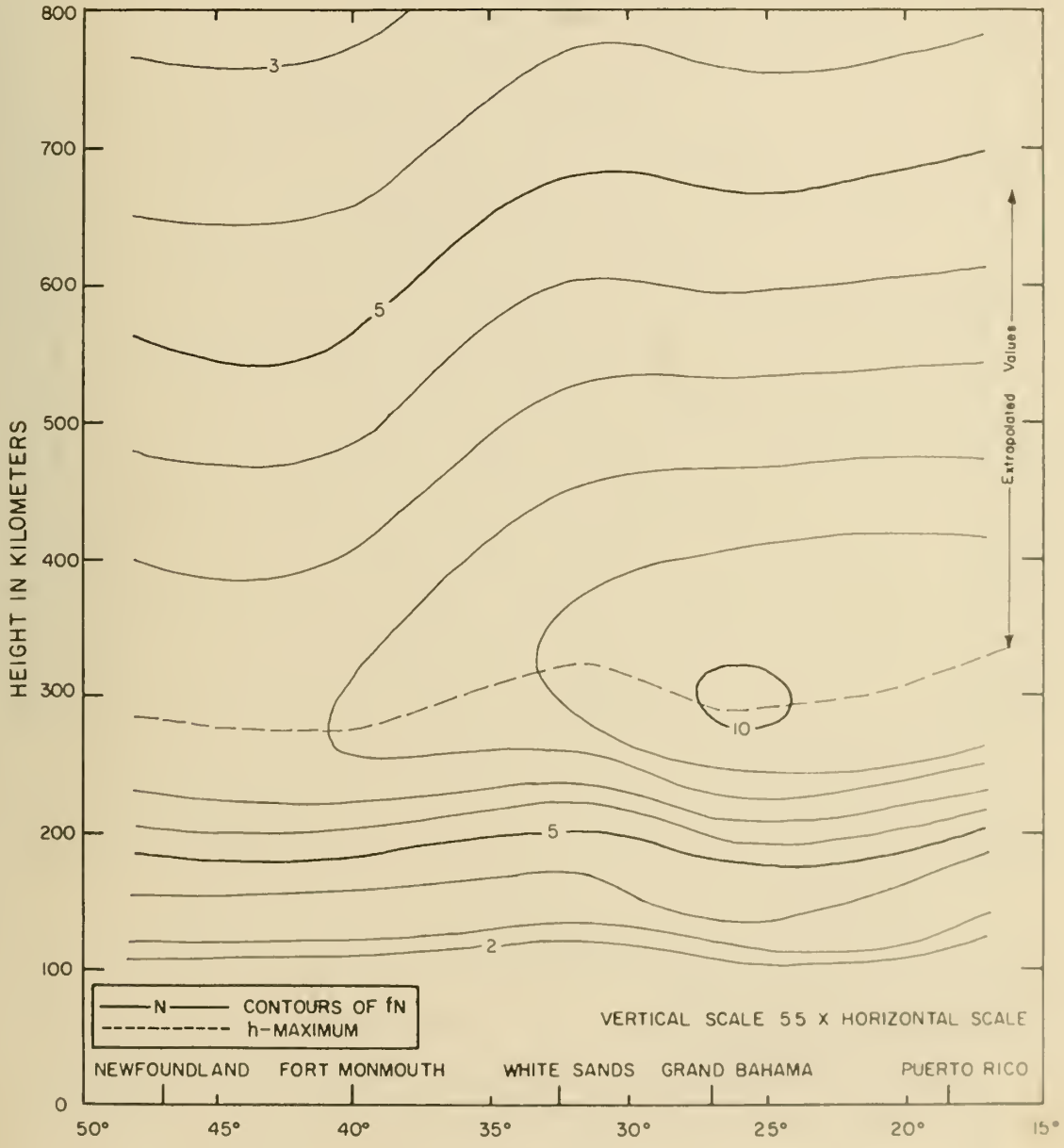
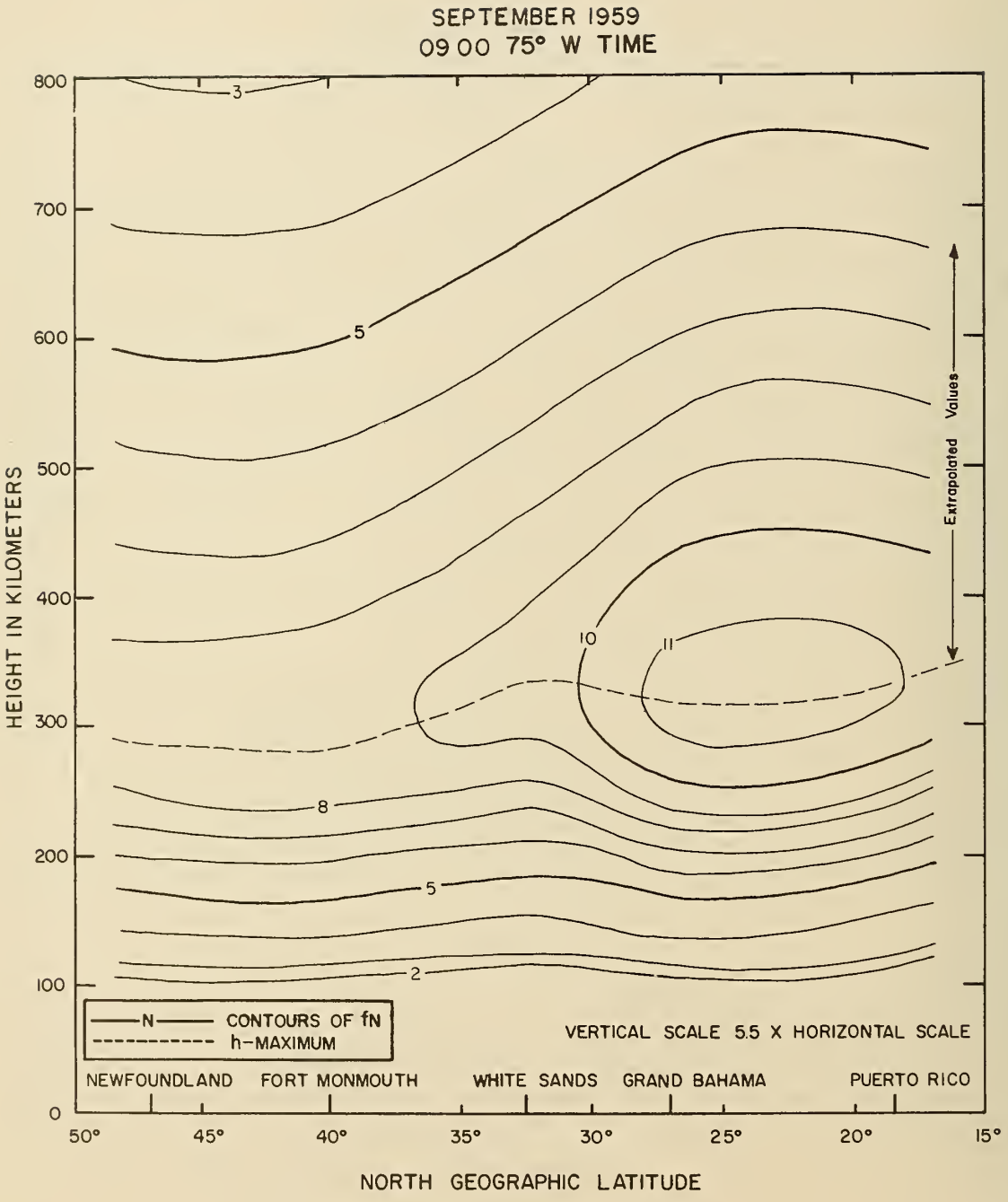
20°
15°
NORTH GEOGRAPHIC LATITUDE

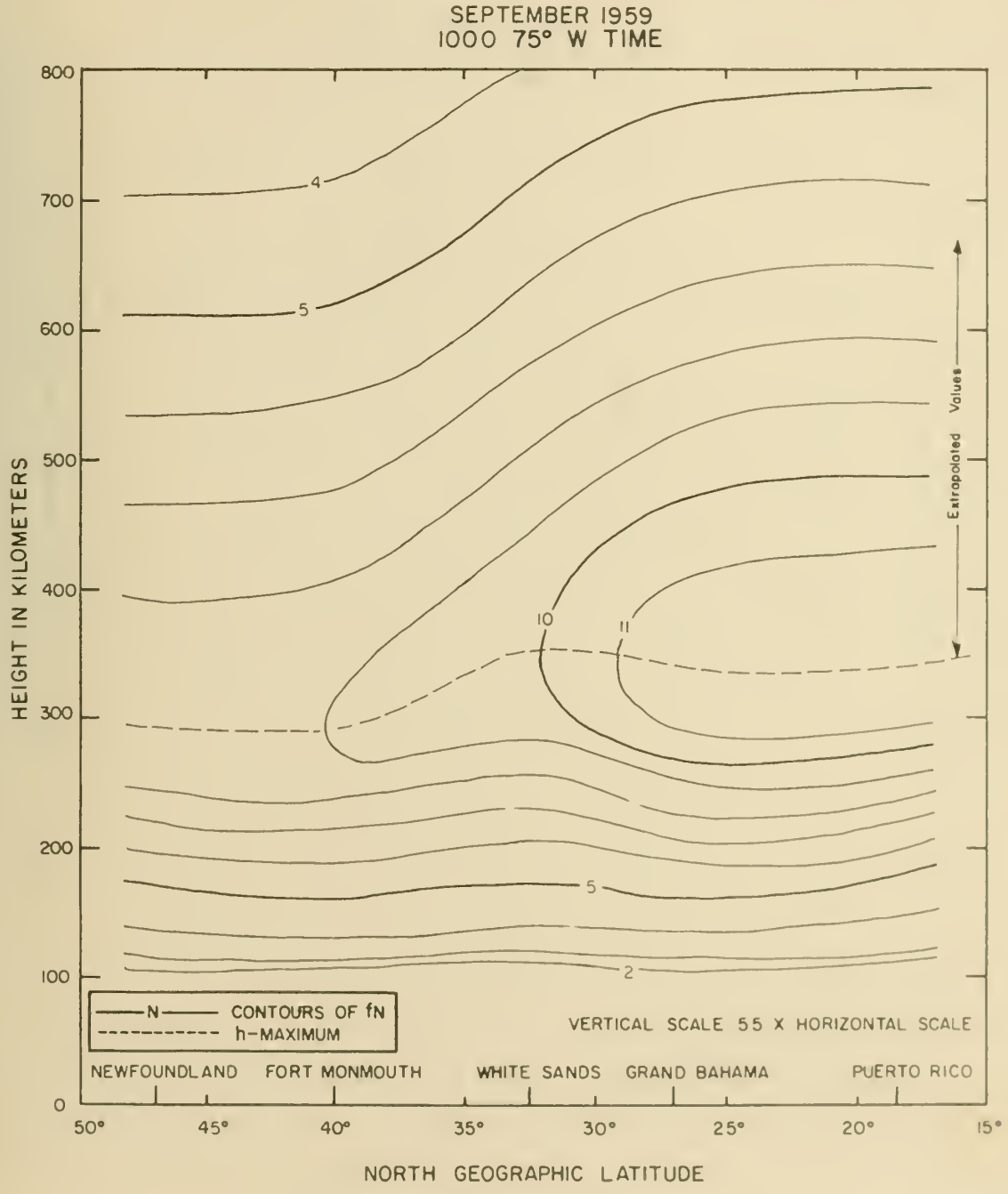

SEPTEMBER 1959
0600 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
2
5
6
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 55 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

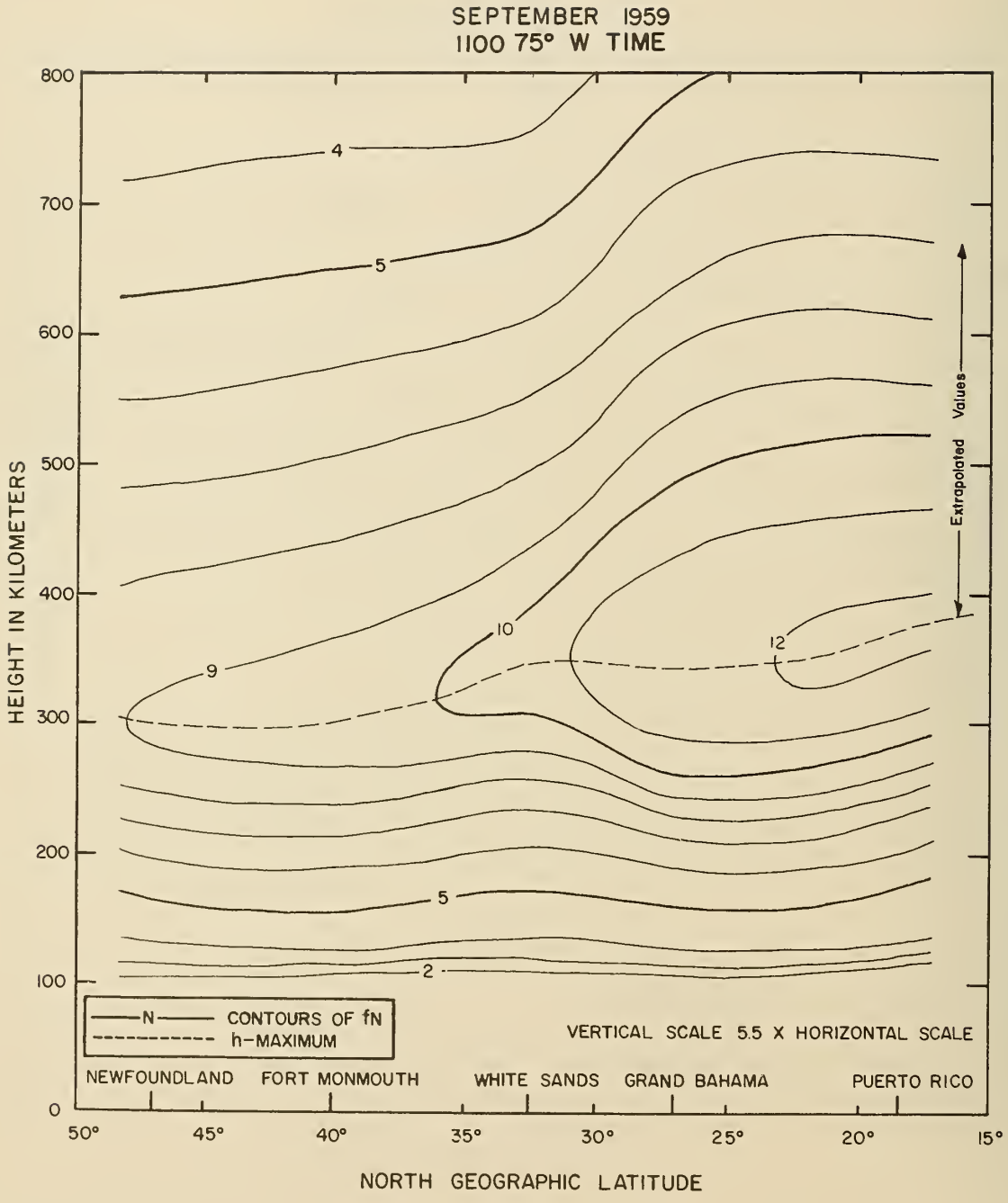

SEPTEMBER 1959
0700 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
5
8
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

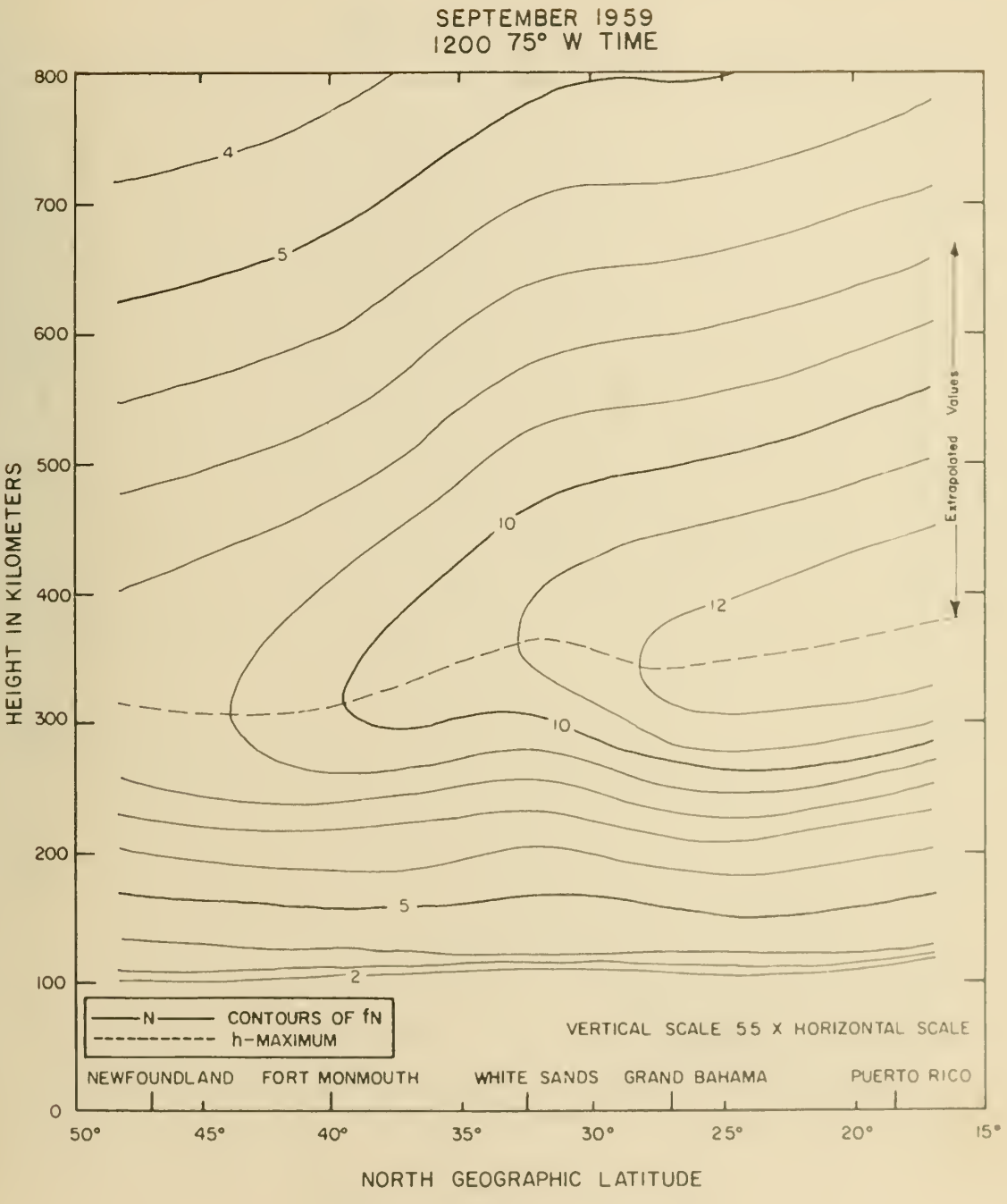
SEPTEMBER 1959
0800 75° W TIME

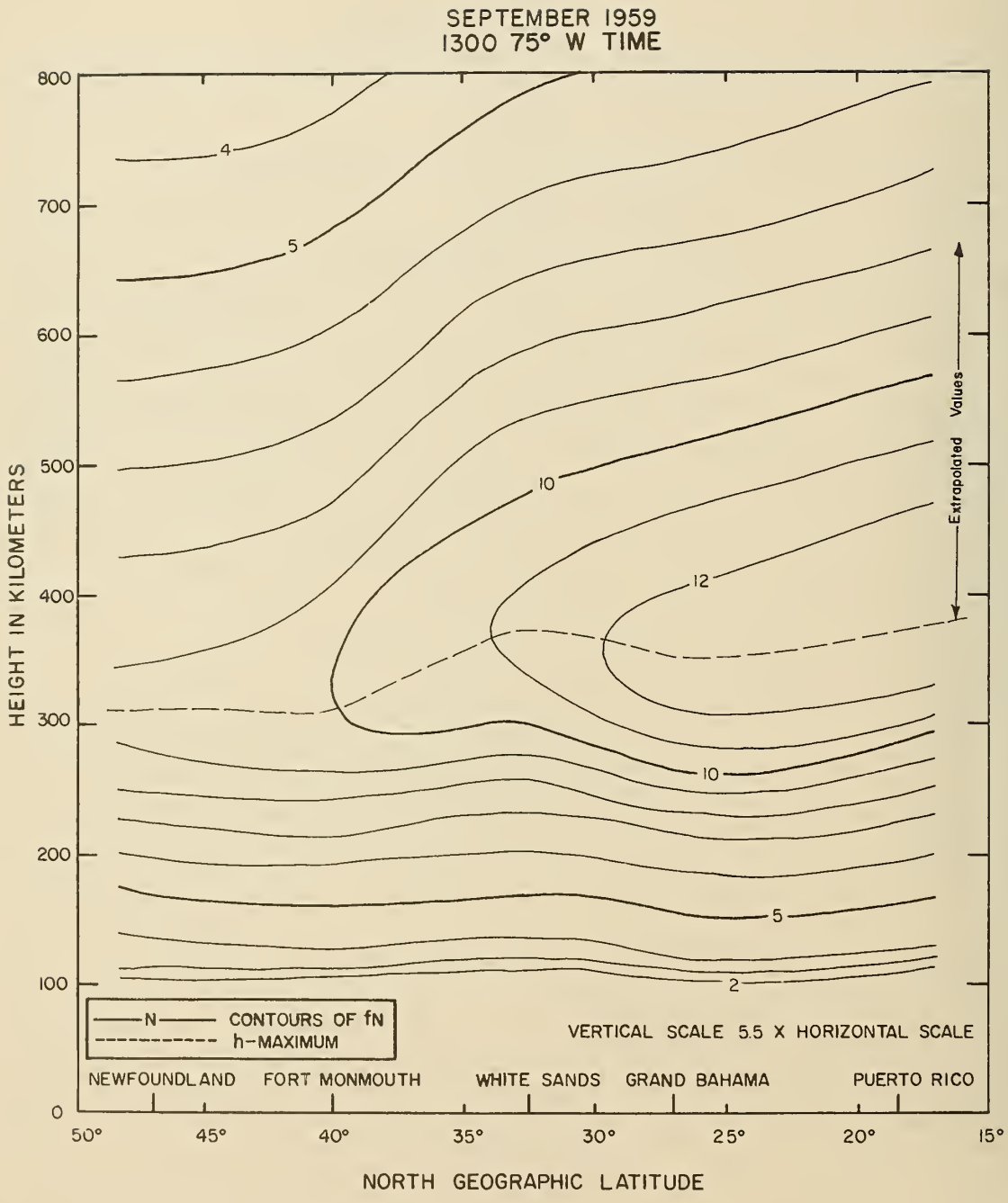


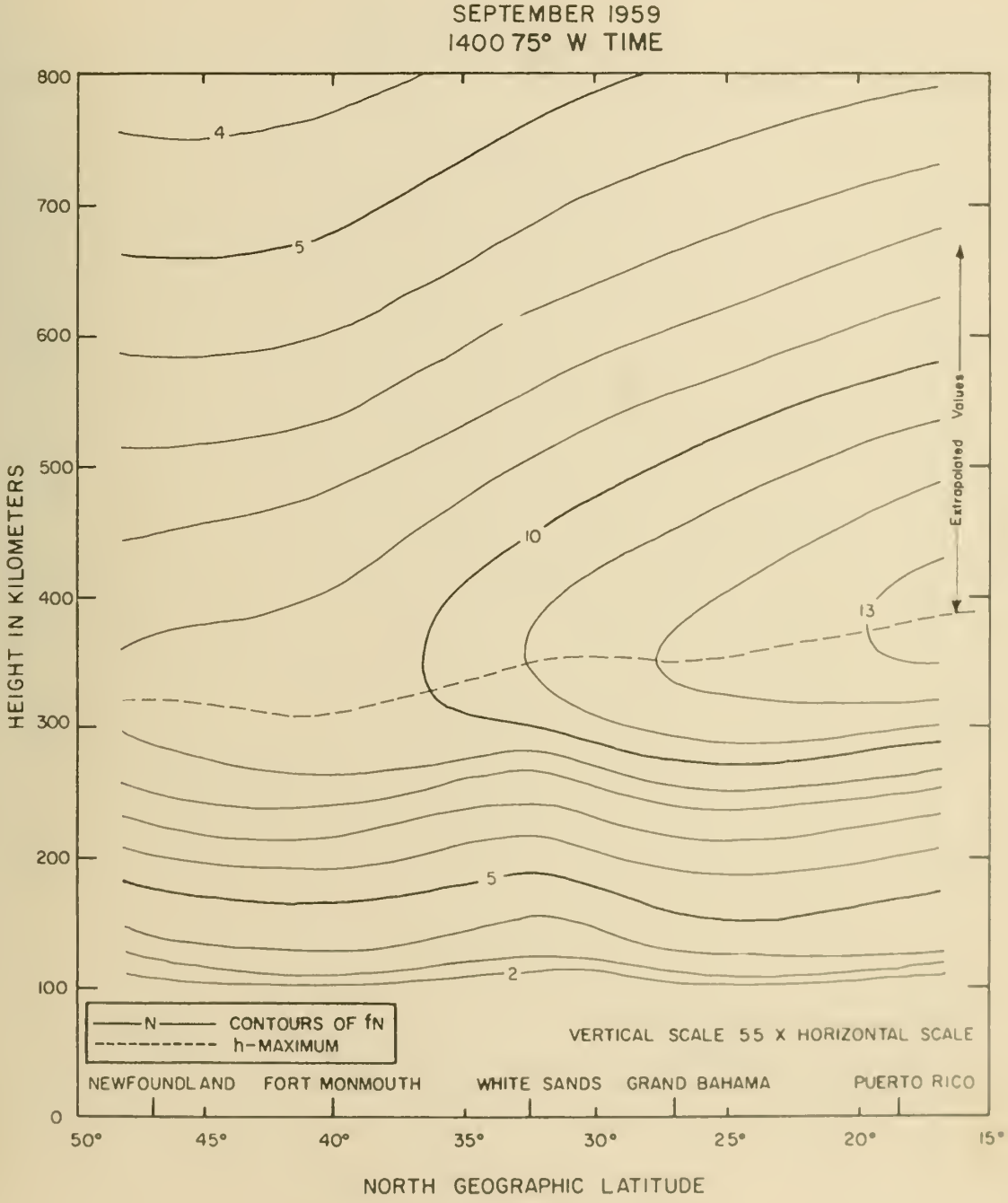

SEPTEMBER 1959
09 00 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
5
10
11
8
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

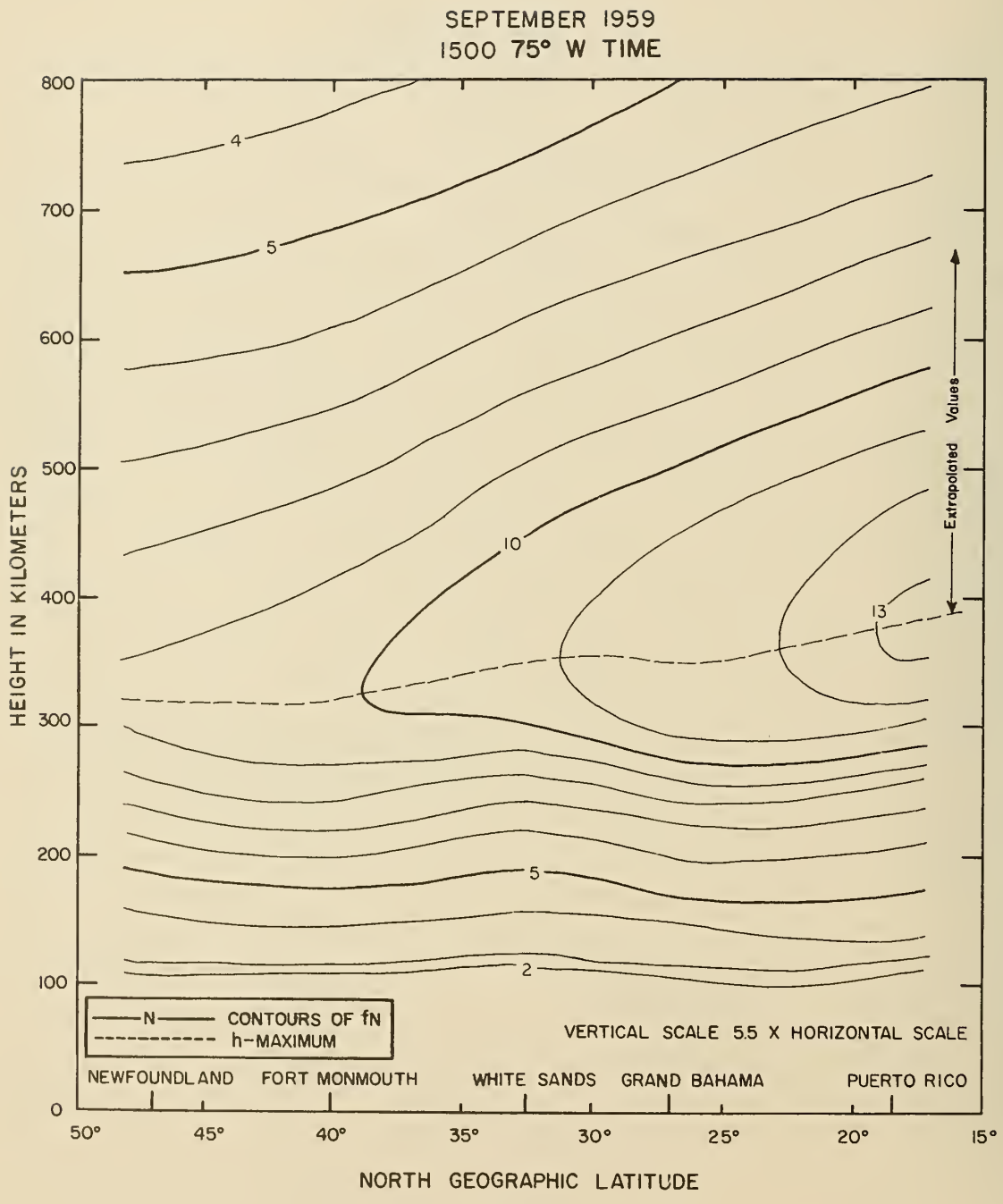

SEPTEMBER 1959
1000 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
11
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 55 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

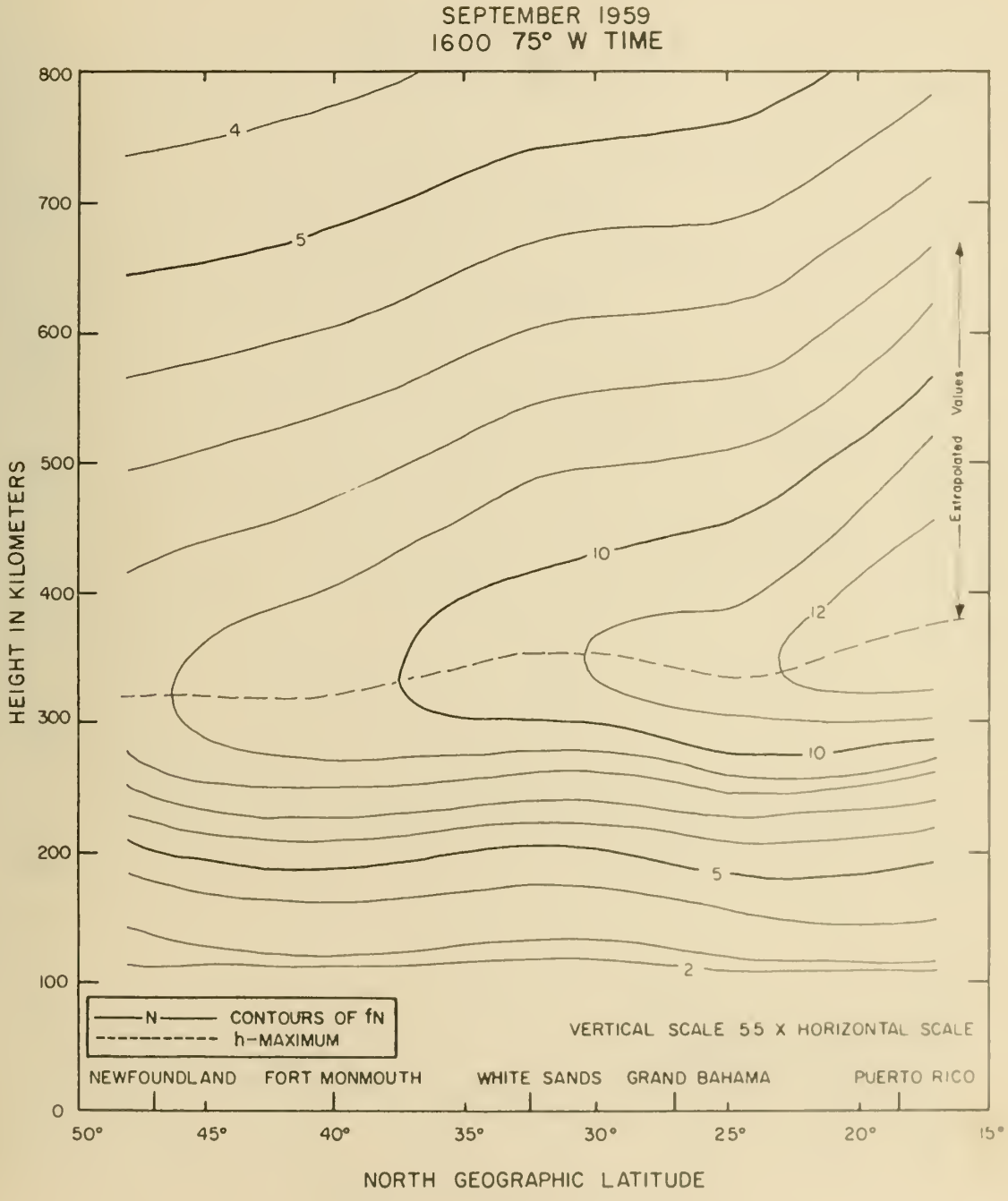

SEPTEMBER 1959
1100 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
9
10
12
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


SEPTEMBER 1959
1200 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
12
10
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 55 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


SEPTEMBER 1959
1300 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
12
10
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


SEPTEMBER 1959
1400 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
13
5
2
Extrapolated Values
—N— CONTOURS OF fN
---------- h-MAXIMUM
VERTICAL SCALE 55 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


SEPTEMBER 1959
1500 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
13
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE


SEPTEMBER 1959
1600 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
12
10
5
2
Extrapolated Values
—N— CONTOURS OF fN
---------- h-MAXIMUM
VERTICAL SCALE 55 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
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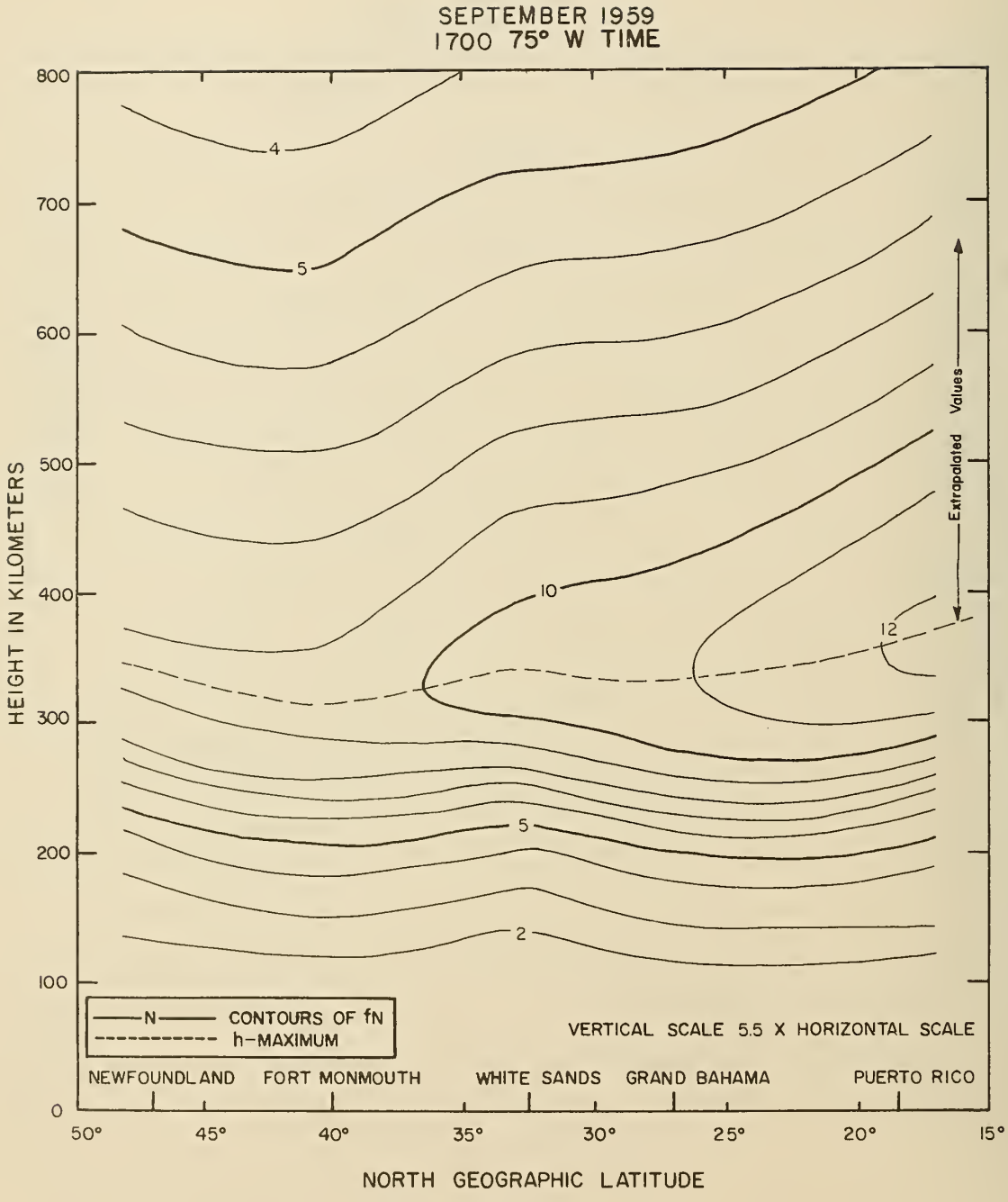
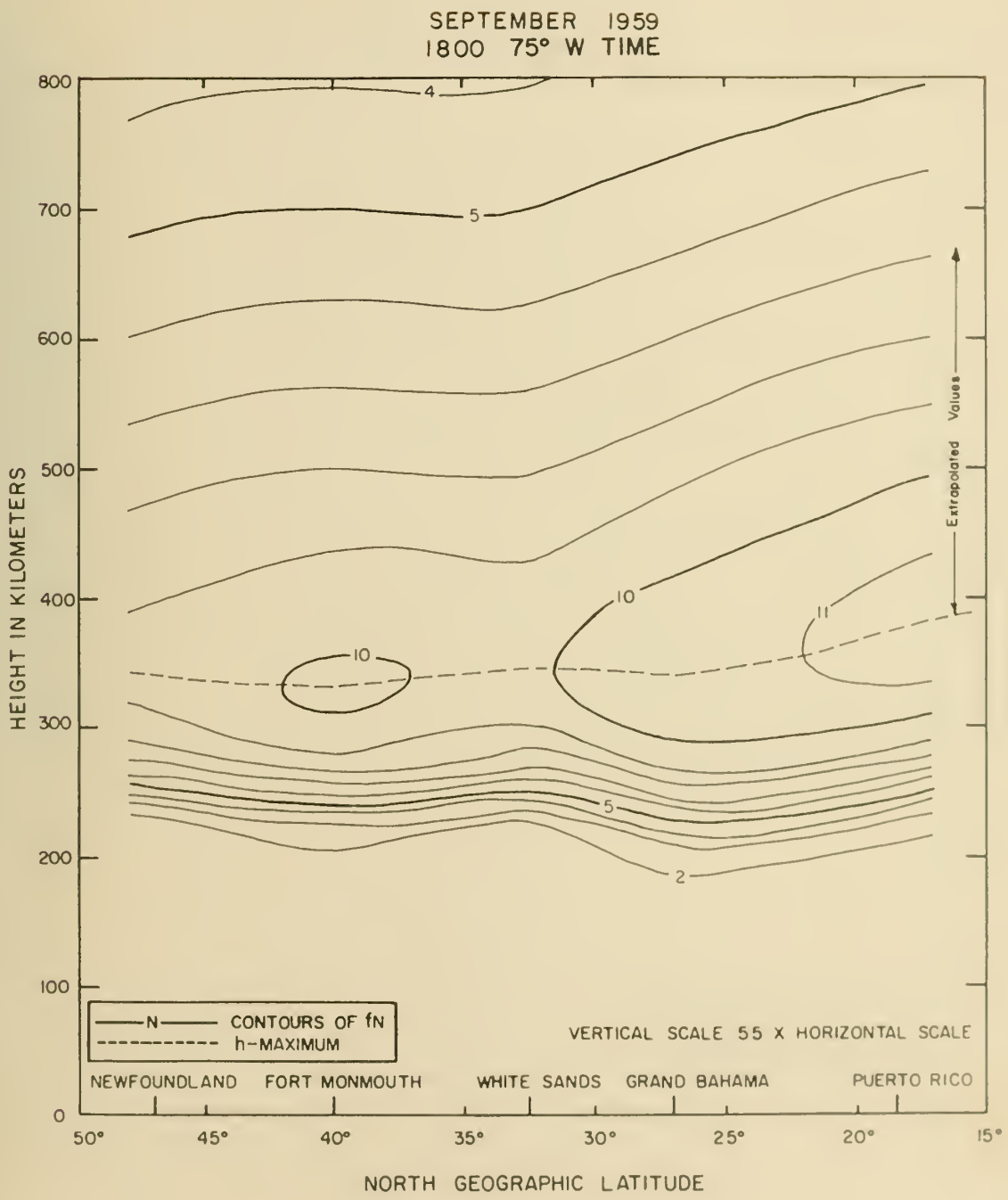
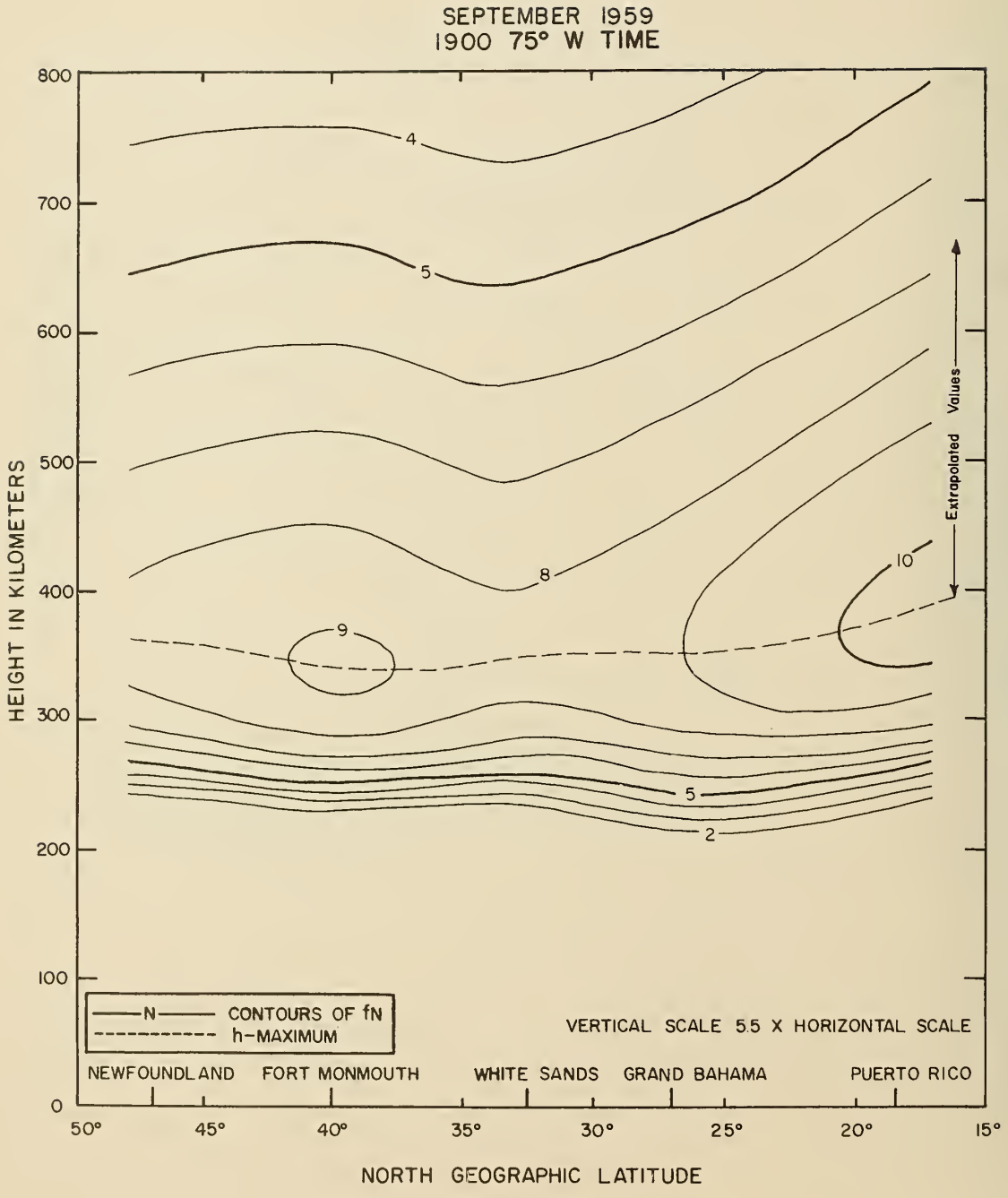
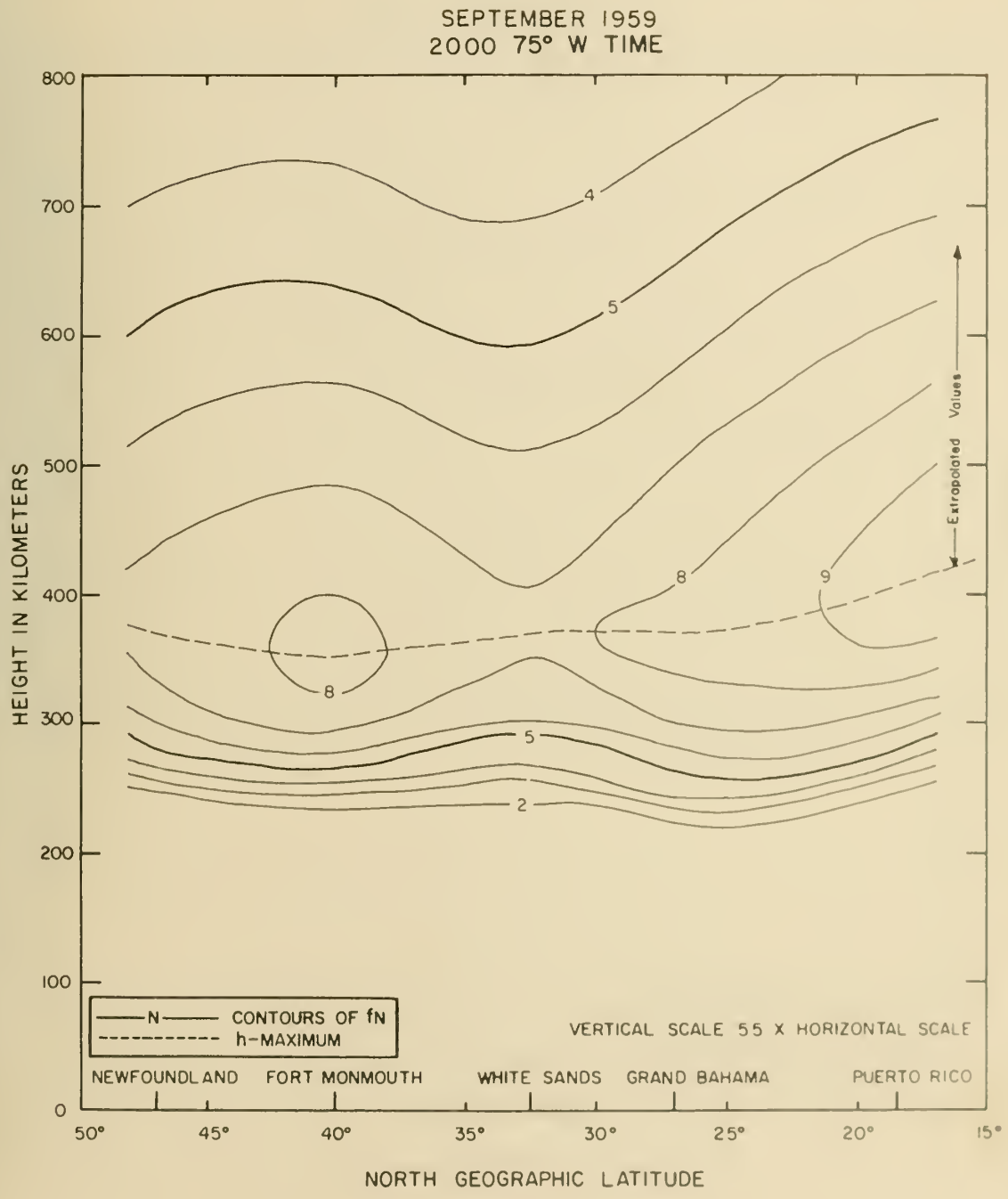
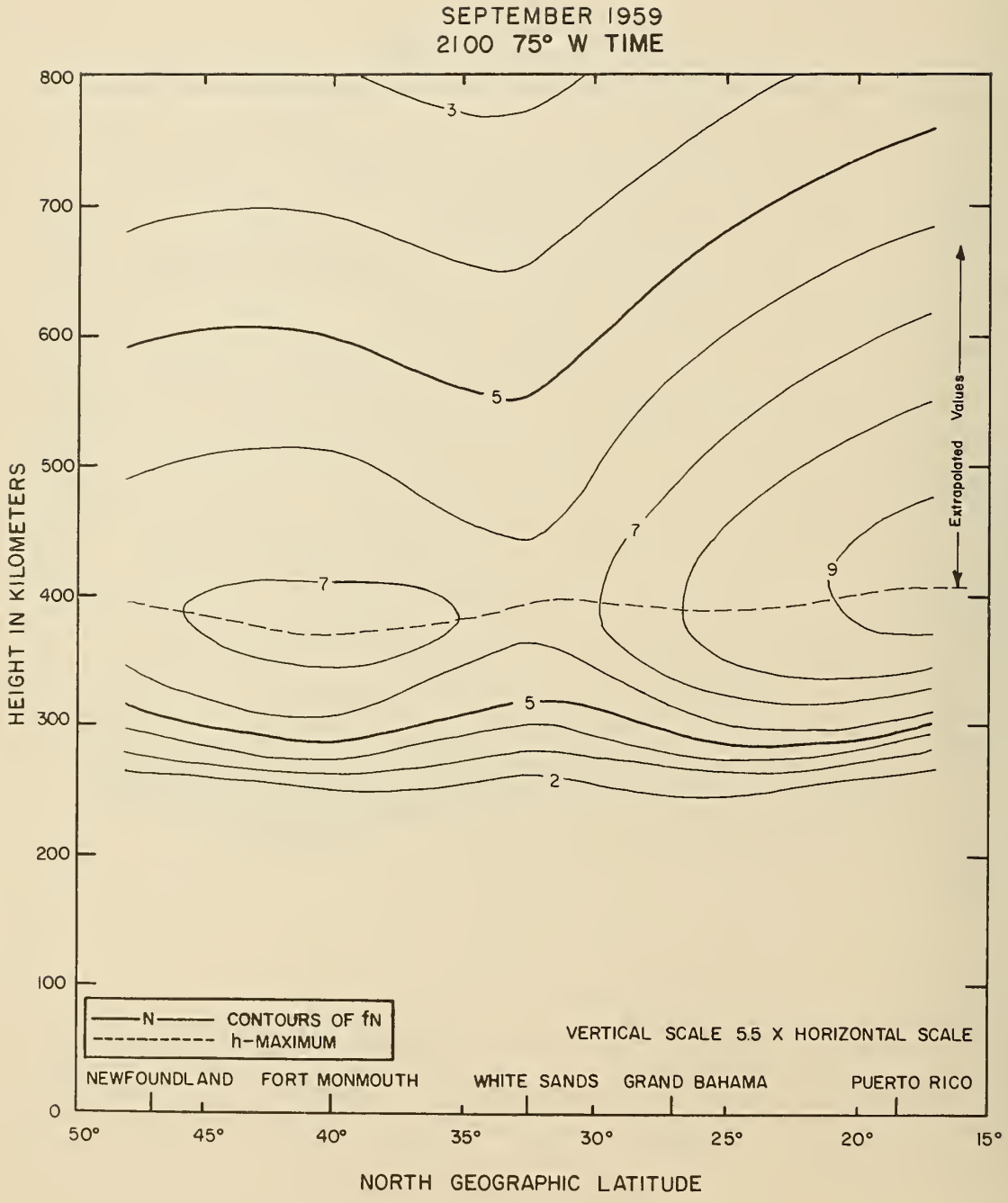
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

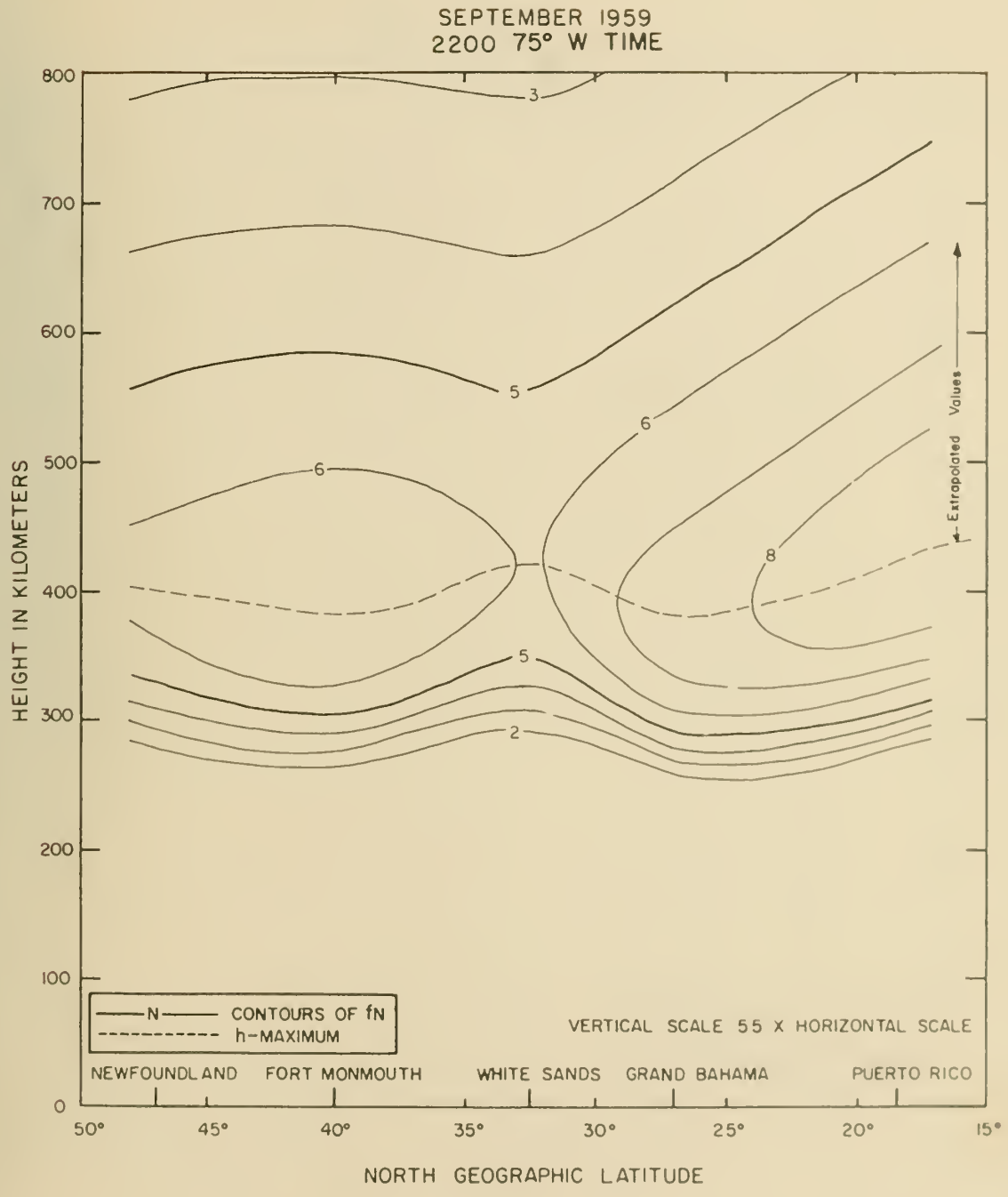

SEPTEMBER 1959
1700 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
12
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

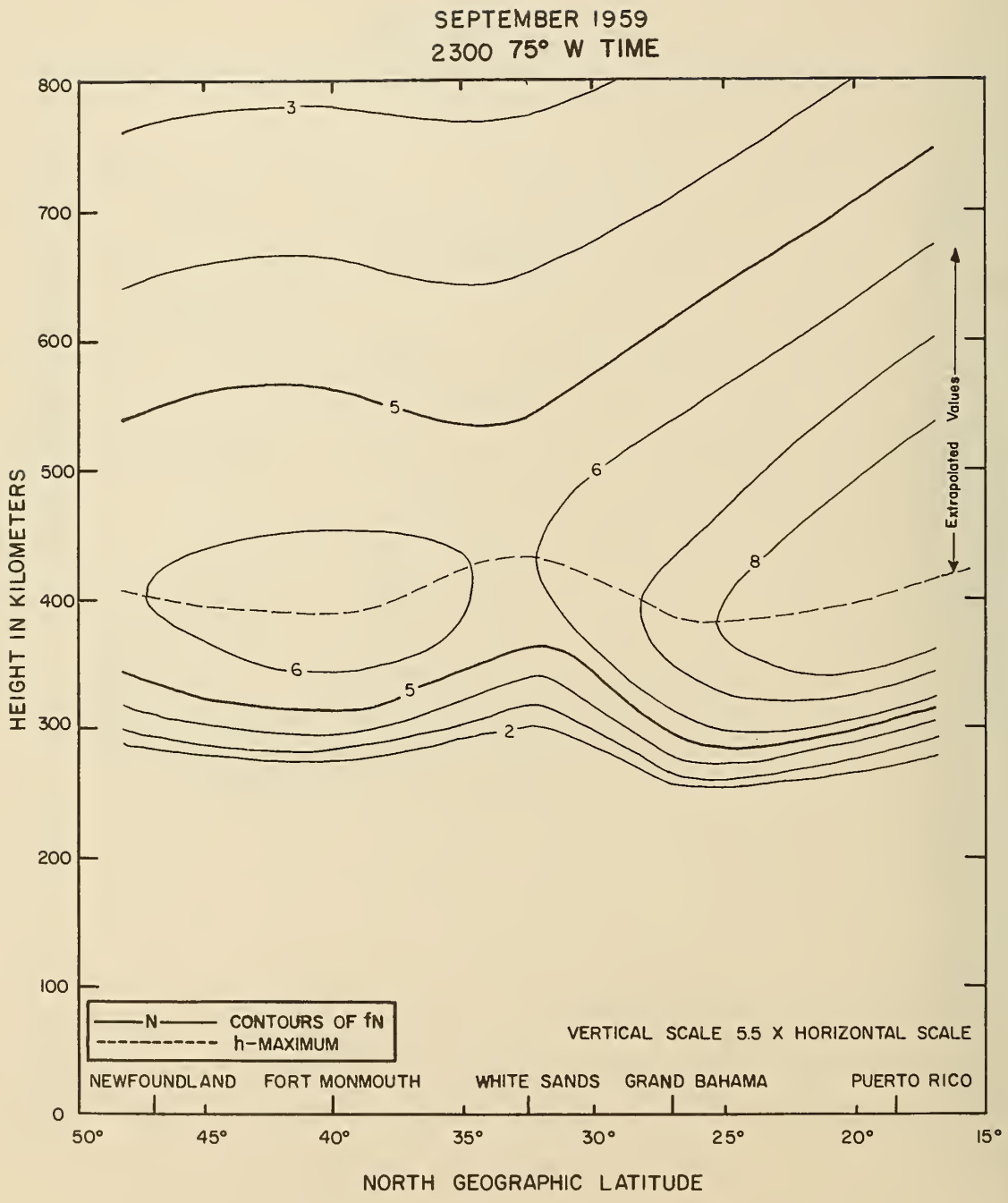

SEPTEMBER 1959
1800 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
10
10
11
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 55 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

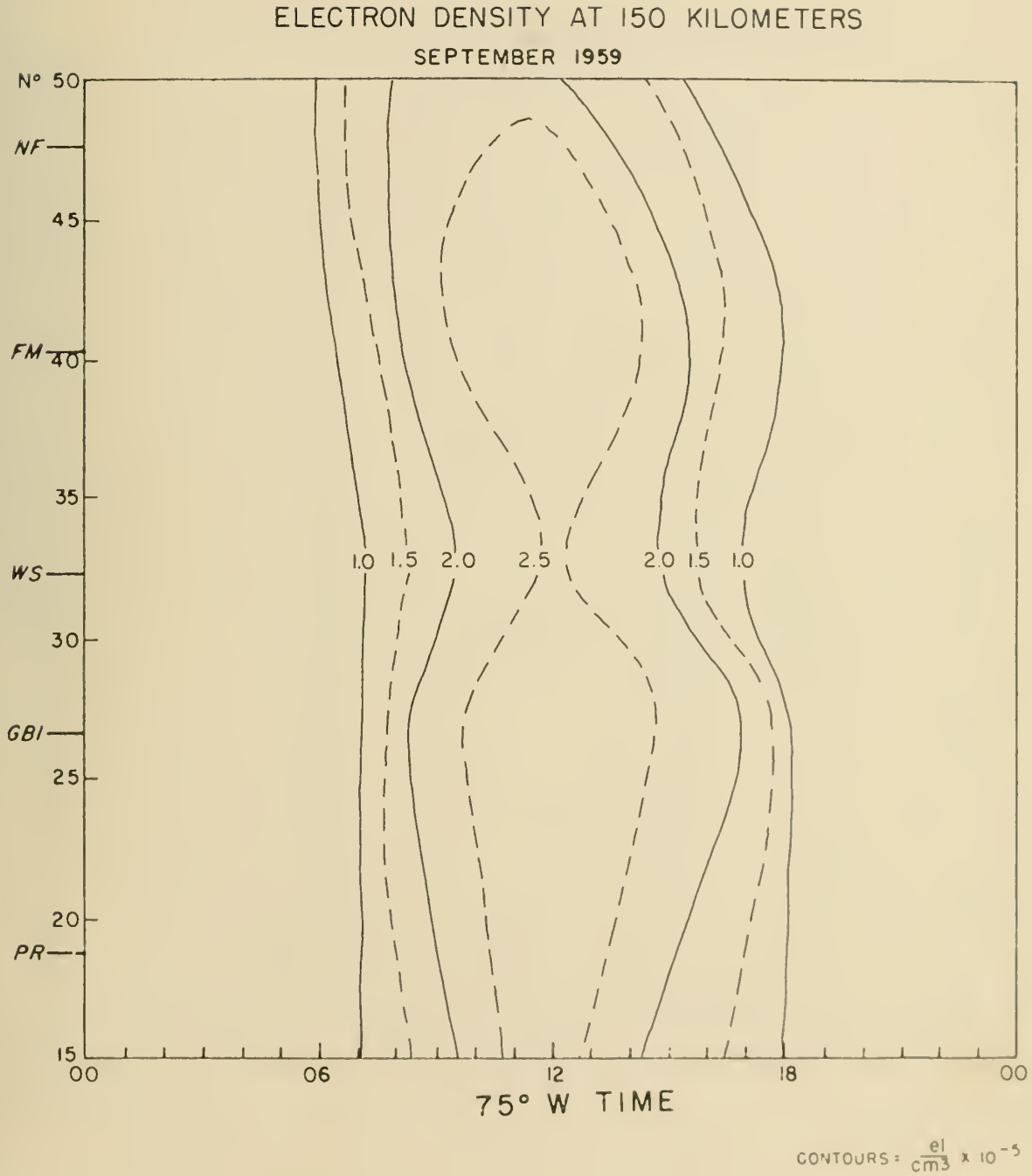

SEPTEMBER 1959
1900 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
8
9
10
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

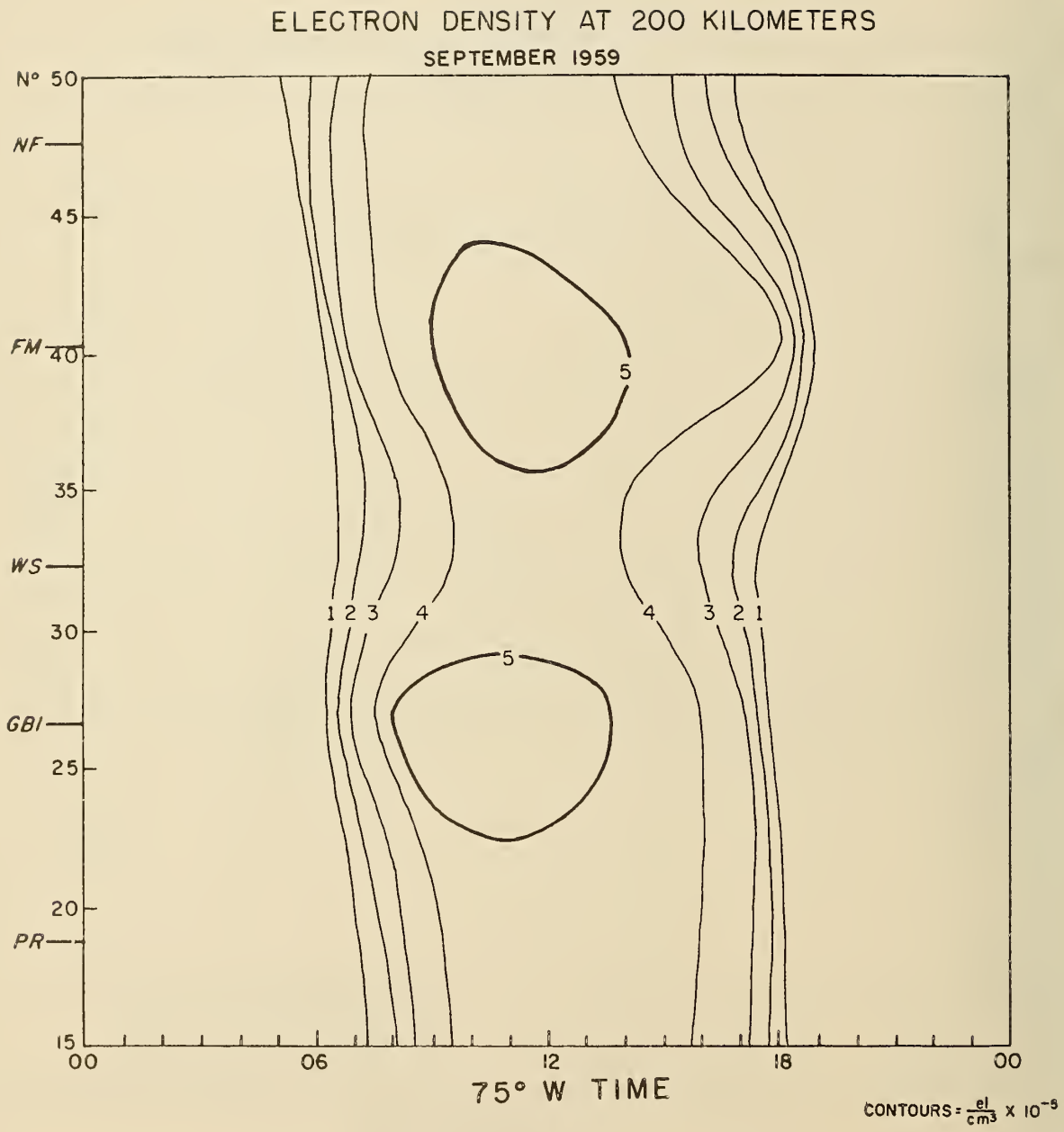

SEPTEMBER 1959
2000 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
8
9
8
5
2
Extrapolated Values
—N— CONTOURS OF fN
---------- h-MAXIMUM
VERTICAL SCALE 55 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

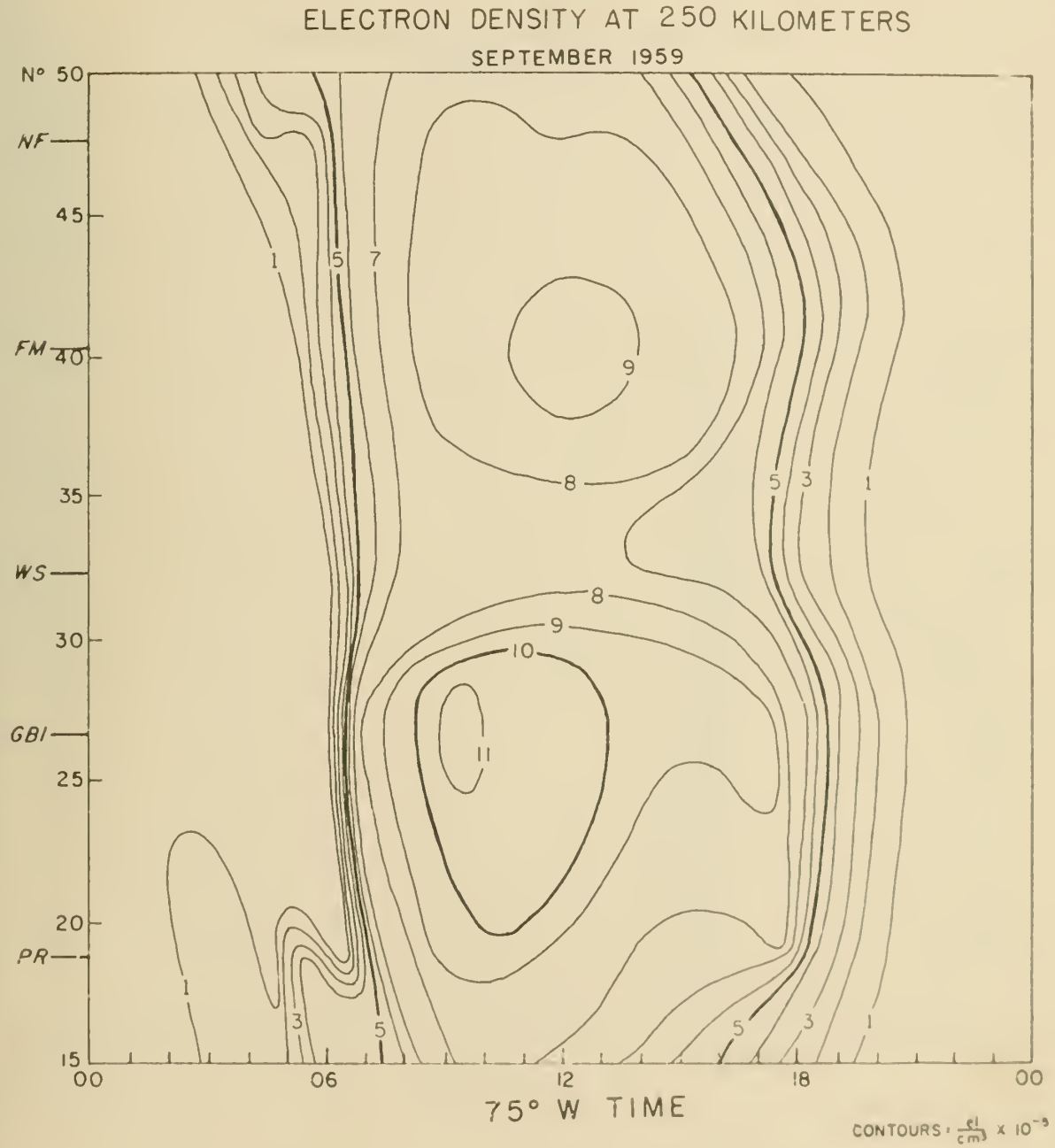

SEPTEMBER 1959
2100 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
5
7
9
7
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

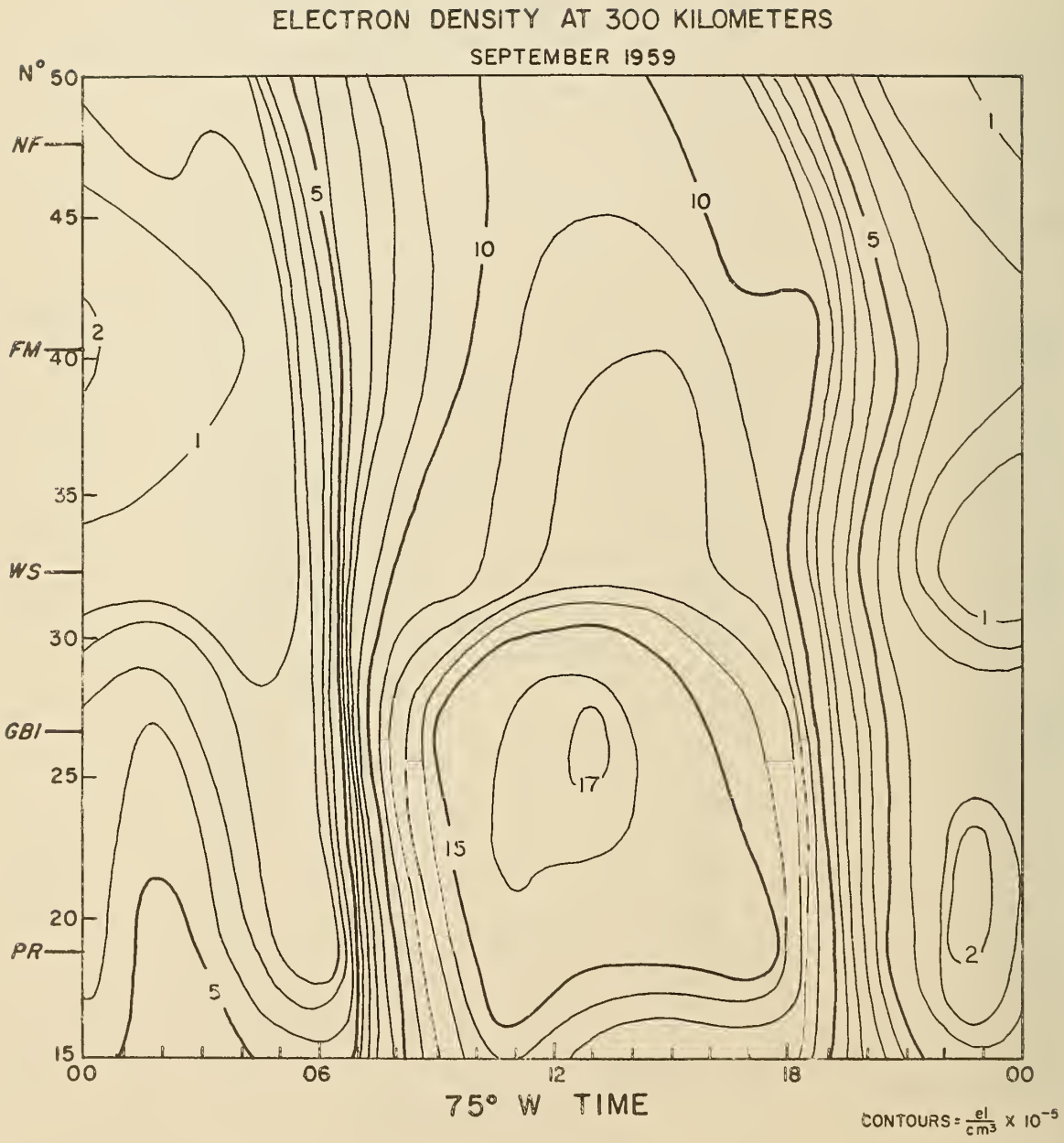

SEPTEMBER 1959
2200 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
5
6
6
8
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 55 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

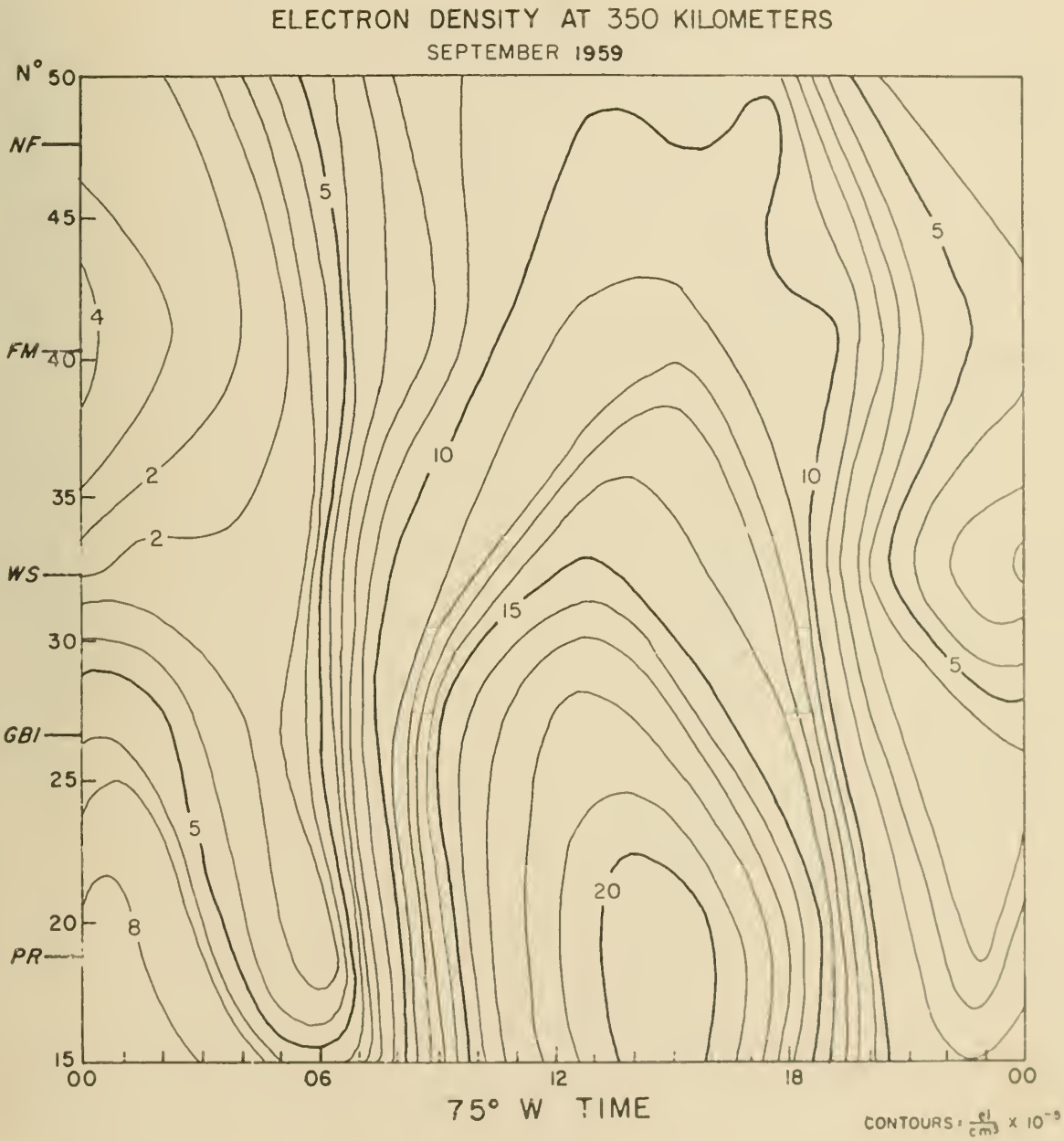

SEPTEMBER 1959
2300 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
5
6
8
6
5
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
NORTH GEOGRAPHIC LATITUDE

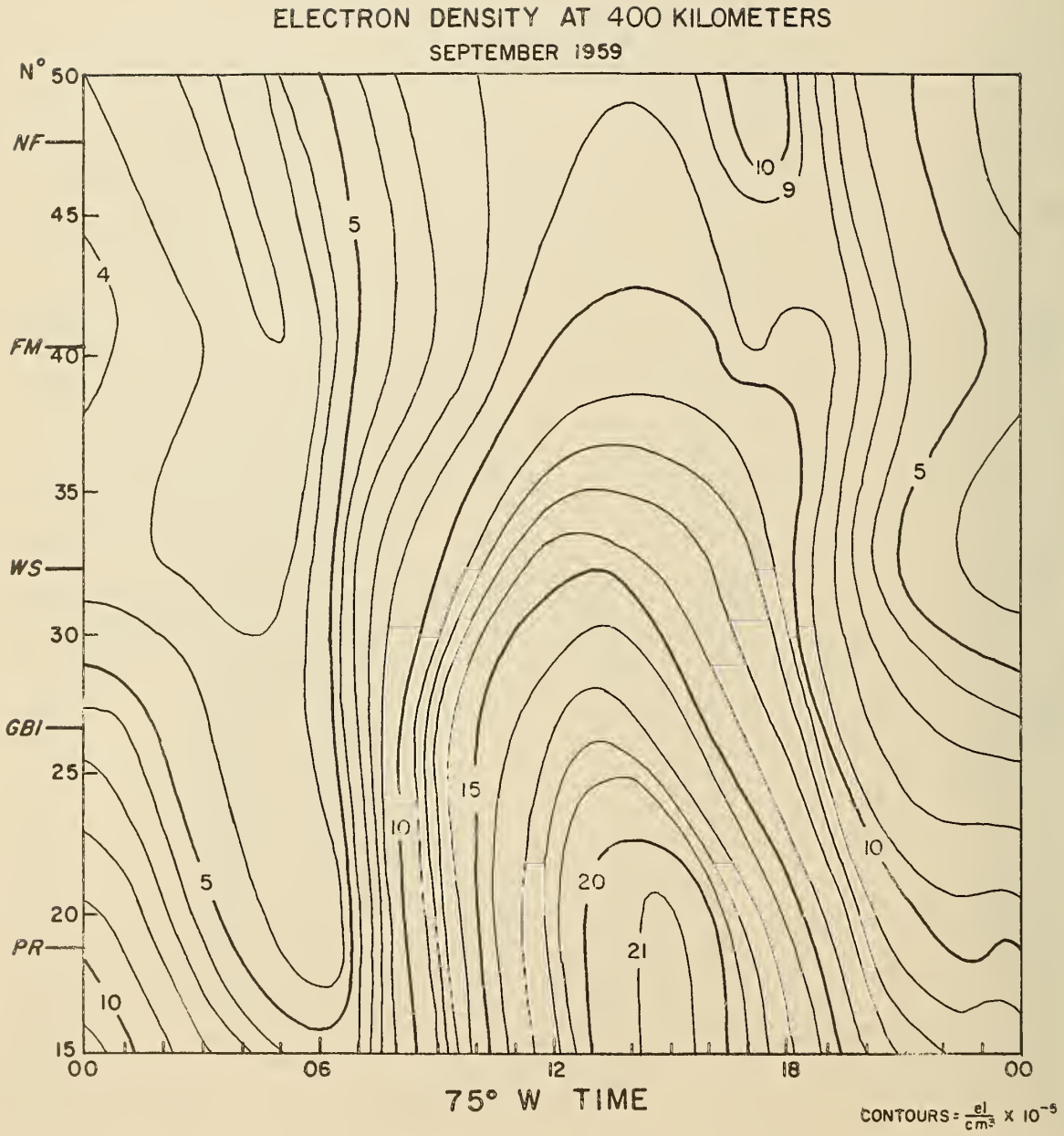

ELECTRON DENSITY AT 150 KILOMETERS
SEPTEMBER 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
1.0 1.5 2.0 2.5 2.0 1.5 1.0
00
06
12
18
00
75° W TIME
CONTOURS = el/cm3 x 10^-5


ELECTRON DENSITY AT 200 KILOMETERS
SEPTEMBER 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
1 2 3 4
5
5
4 3 2 1
00
06
12
18
00
75° W TIME
CONTOURS = el/cm3 x 10⁻⁵


ELECTRON DENSITY AT 250 KILOMETERS
SEPTEMBER 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
00
06
12
18
00
75° W TIME
CONTOURS : el/cm3 x 10^-3
1
5
7
9
8
5
3
1
8
9
10
11
1
3
5
5
3
1


ELECTRON DENSITY AT 300 KILOMETERS
SEPTEMBER 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
00
06
12
18
00
75° W TIME
CONTOURS = el/cm³ x 10⁻⁵
1
2
5
10
15
17

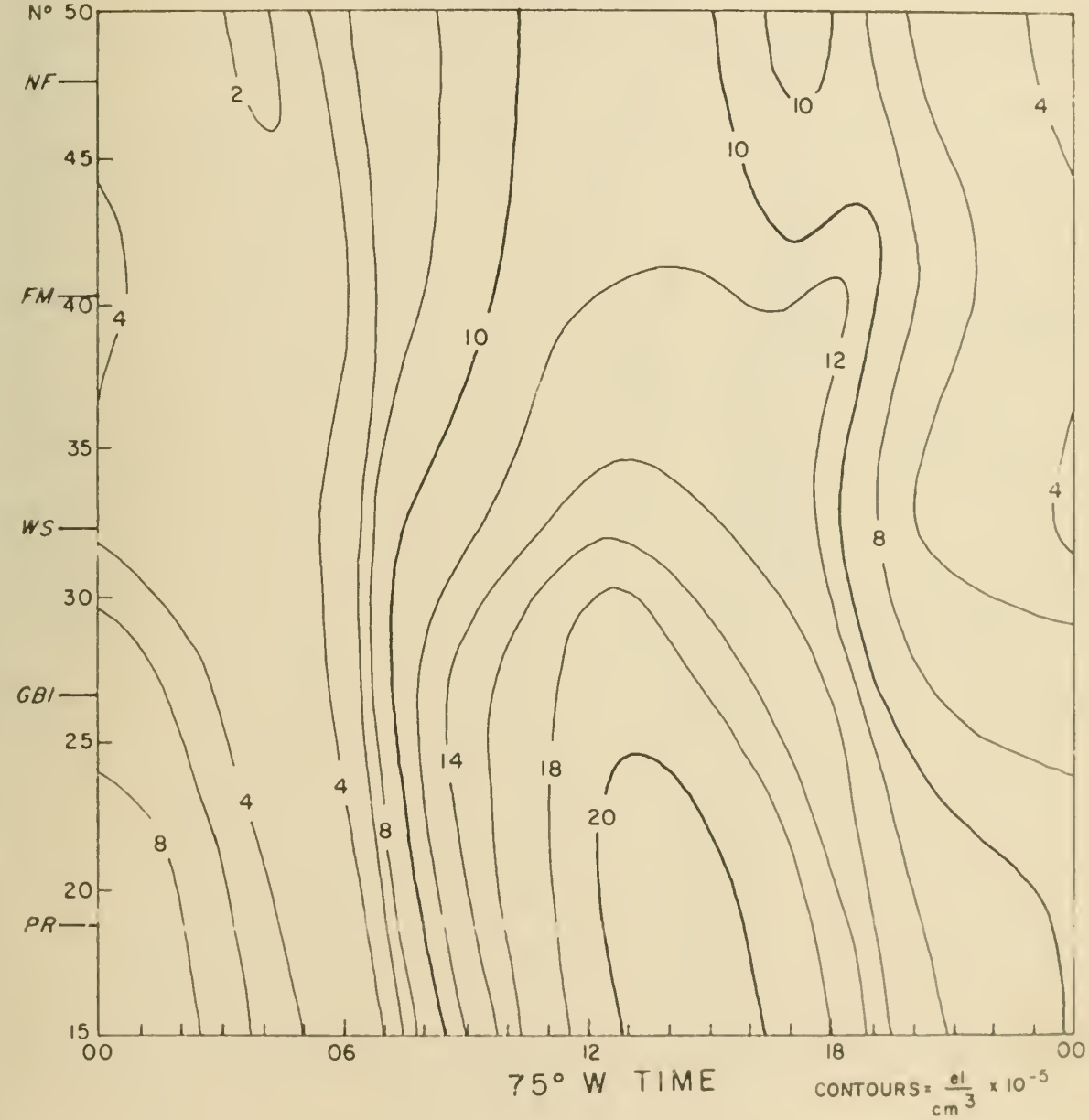

ELECTRON DENSITY AT 350 KILOMETERS
SEPTEMBER 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
00
06
12
18
00
75° W TIME
CONTOURS = el/cm³ x 10⁻³
5
4
2
2
10
10
5
15
5
5
20
8


ELECTRON DENSITY AT 400 KILOMETERS
SEPTEMBER 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
00
06
12
18
00
75° W TIME
CONTOURS = el/cm³ X 10⁻⁵
4
5
9
10
15
20
21

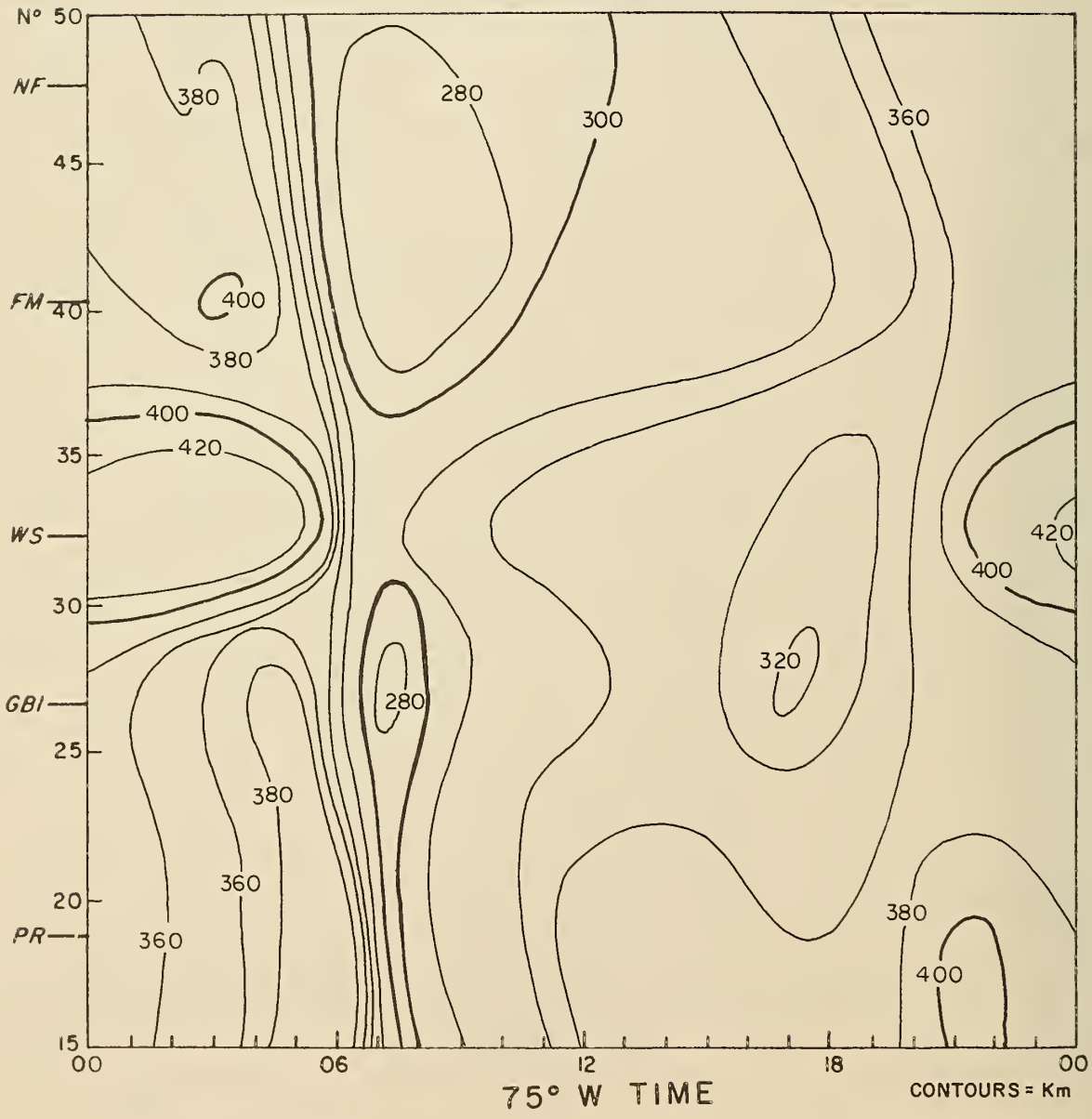
MAXIMUM ELECTRON DENSITY

NMAX

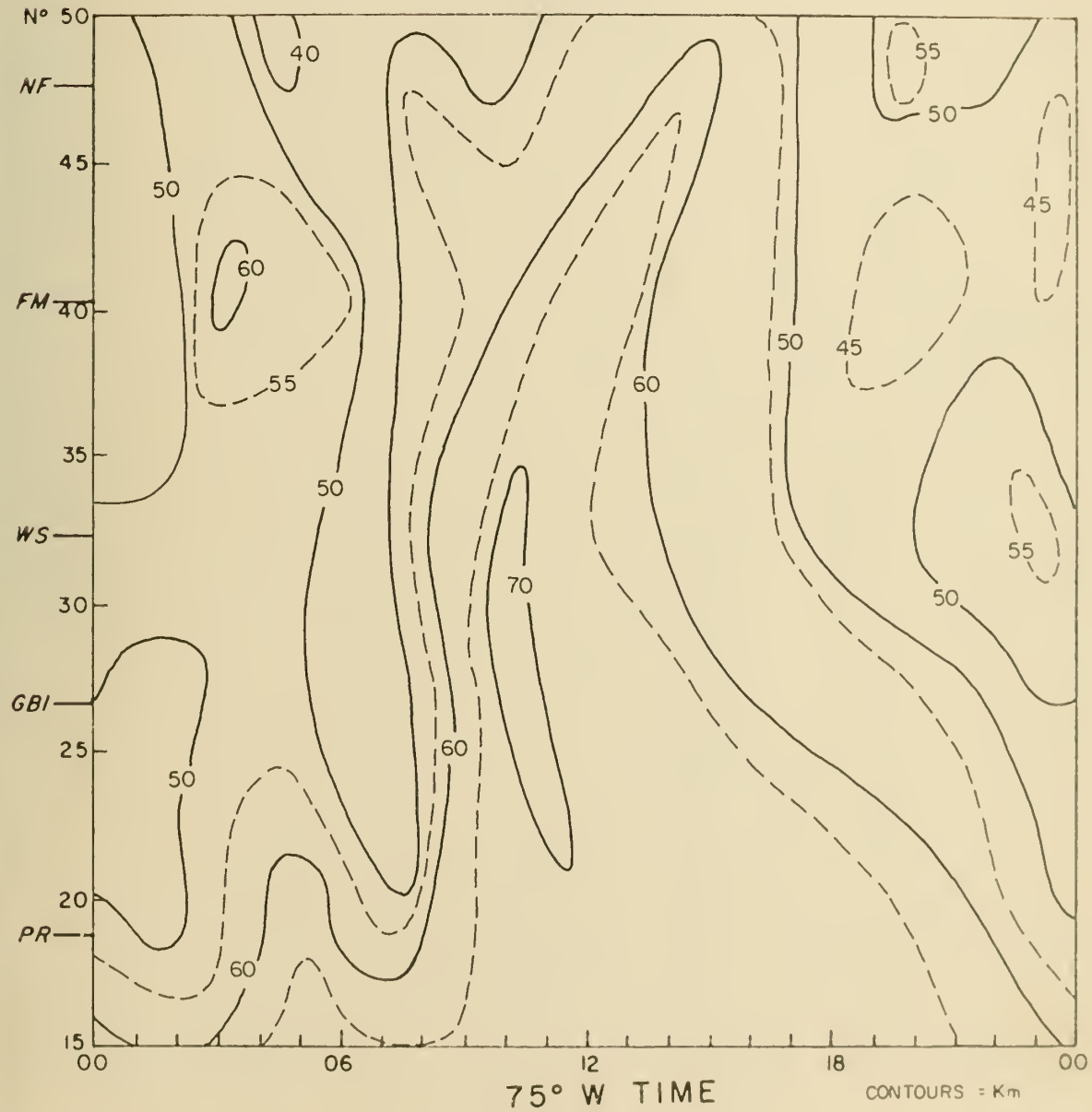
SEPTEMBER 1959



HEIGHT OF MAXIMUM ELECTRON DENSITY
HMAX
SEPTEMBER 1959

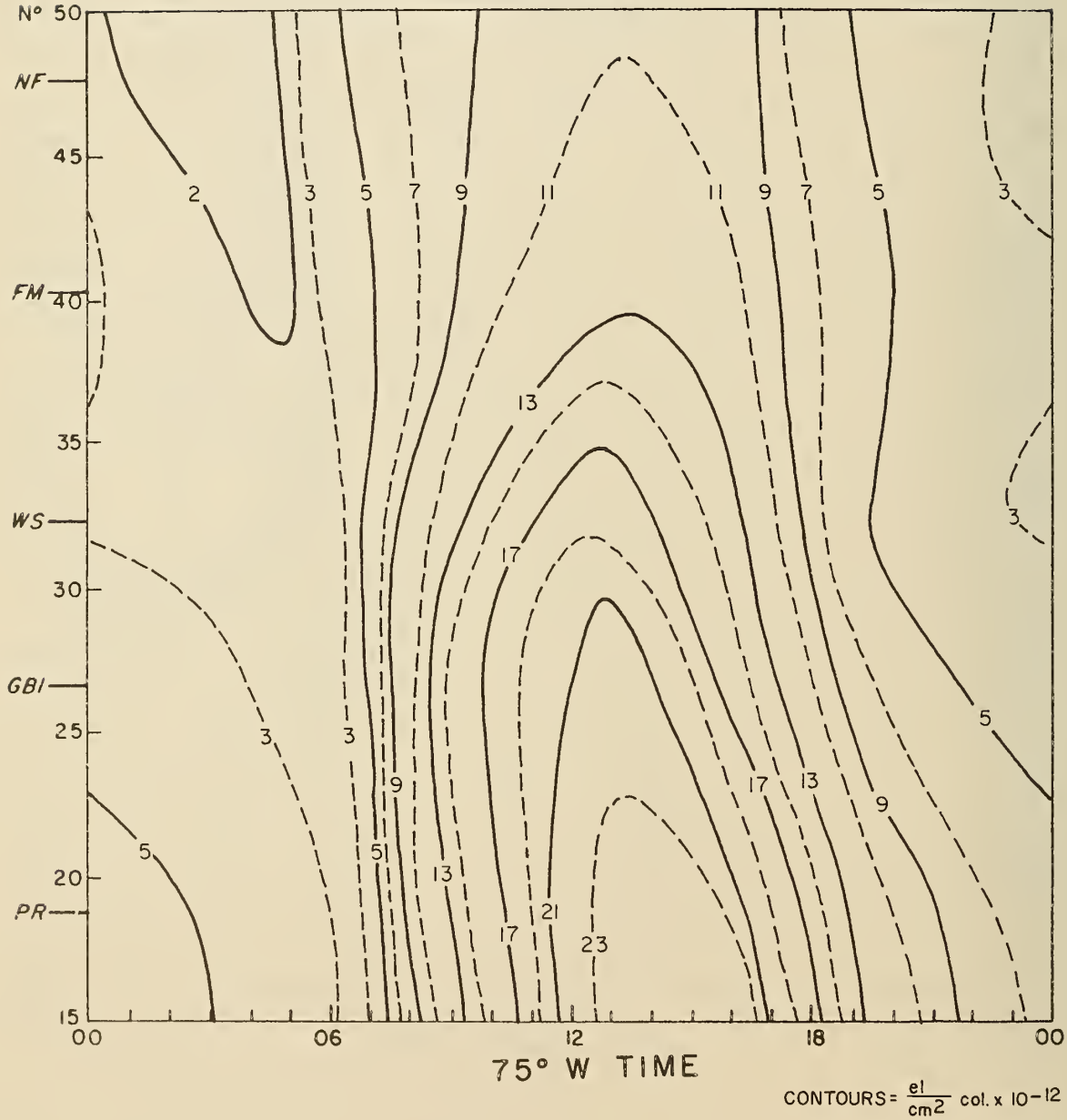


QUARTER THICKNESS OF F-REGION PEAK
SCAT
SEPTEMBER 1959



ELECTRON DENSITY INTEGRATED TO HEIGHT OF MAXIMUM ELECTRON DENSITY SHMAX

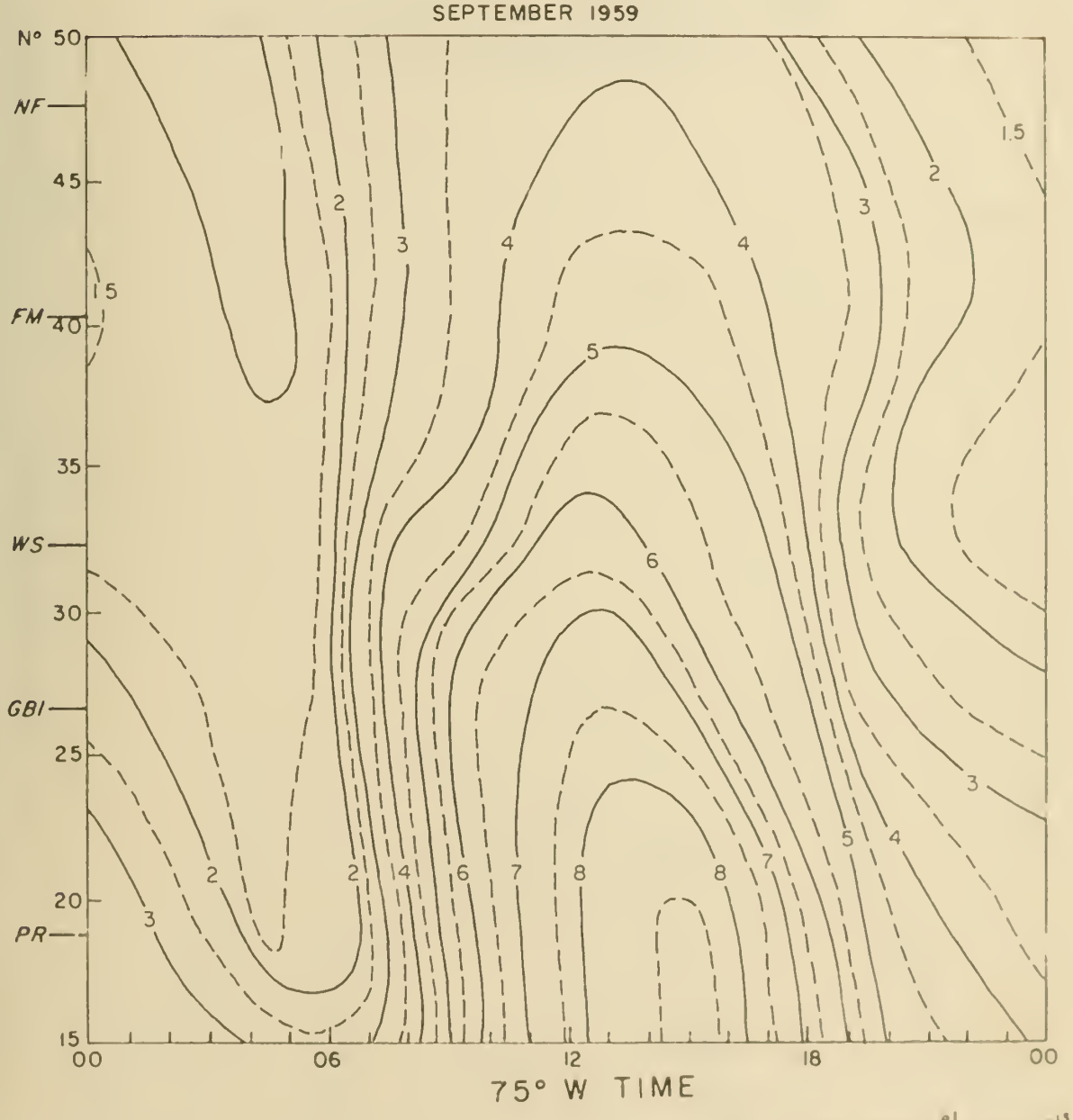
SEPTEMBER 1959

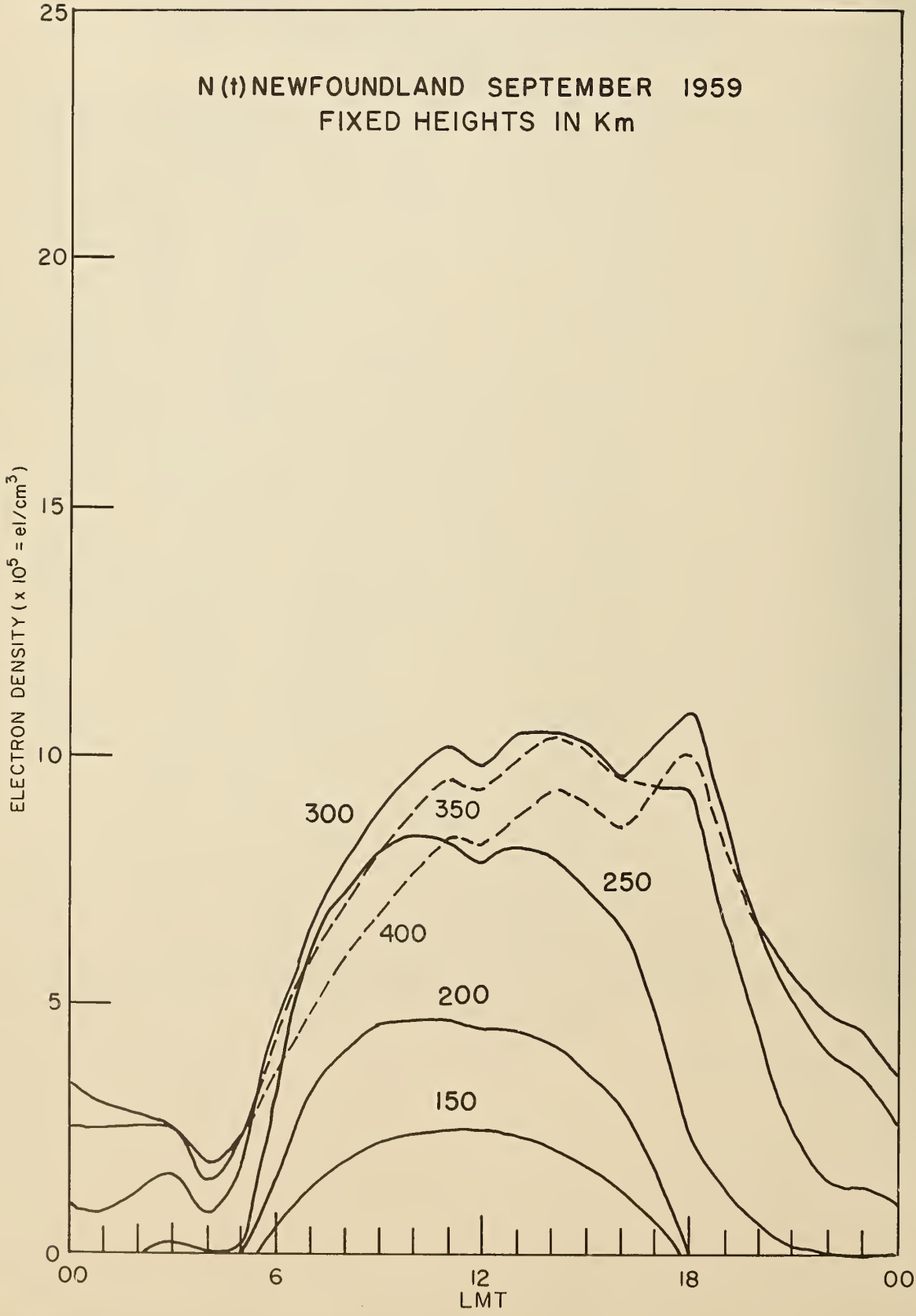


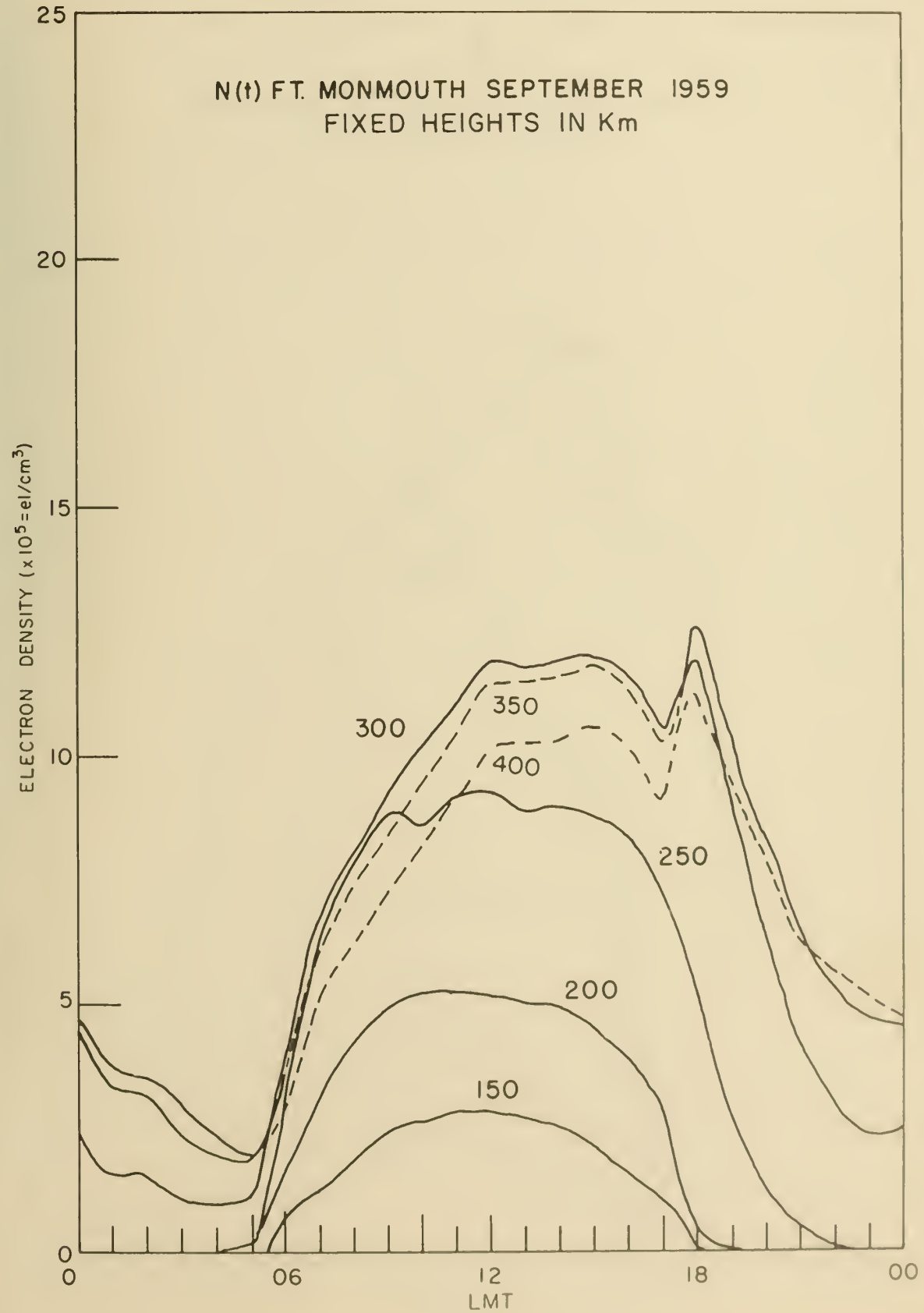
ELECTRON DENSITY INTEGRATED TO INFINITY

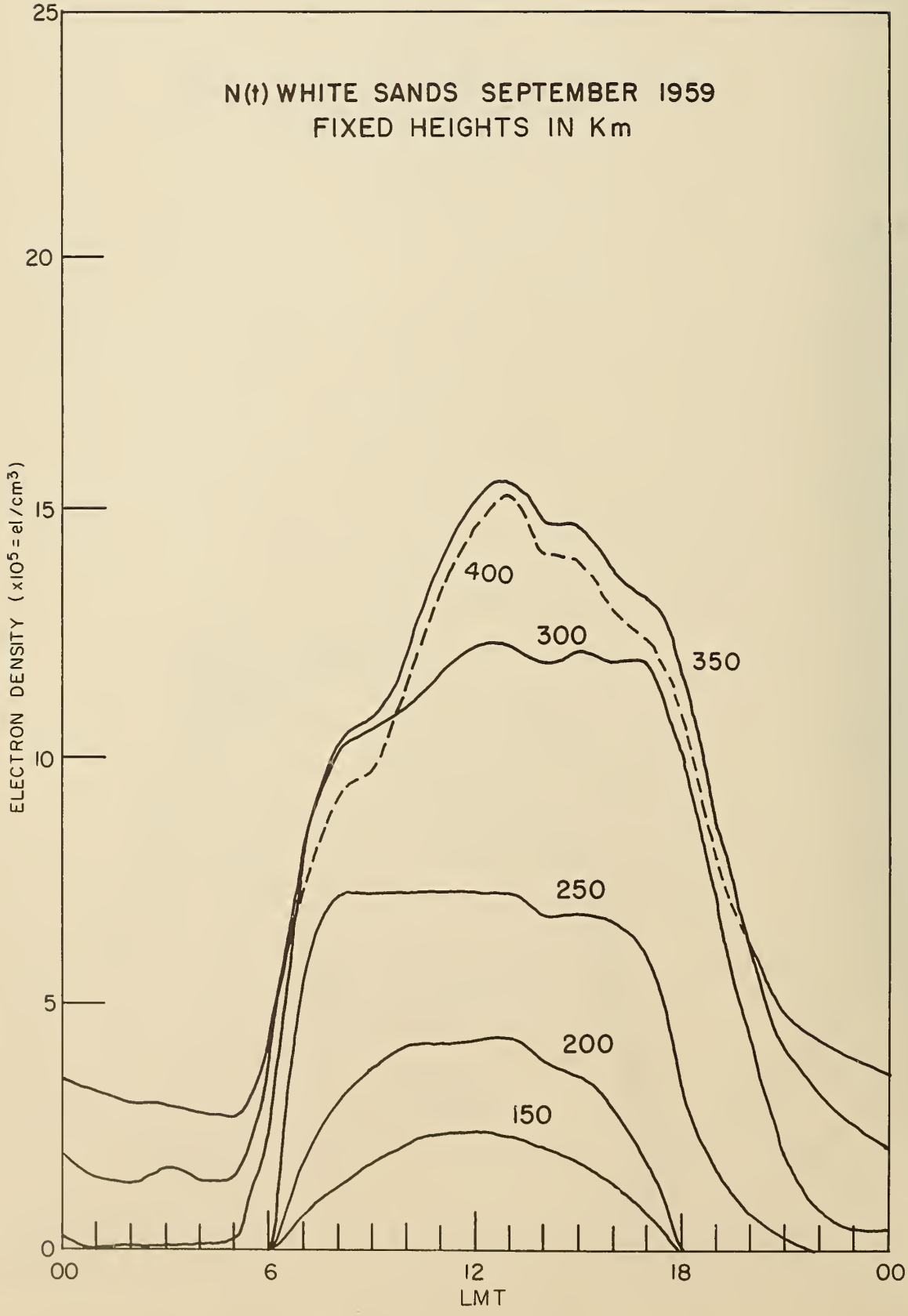
SHINF

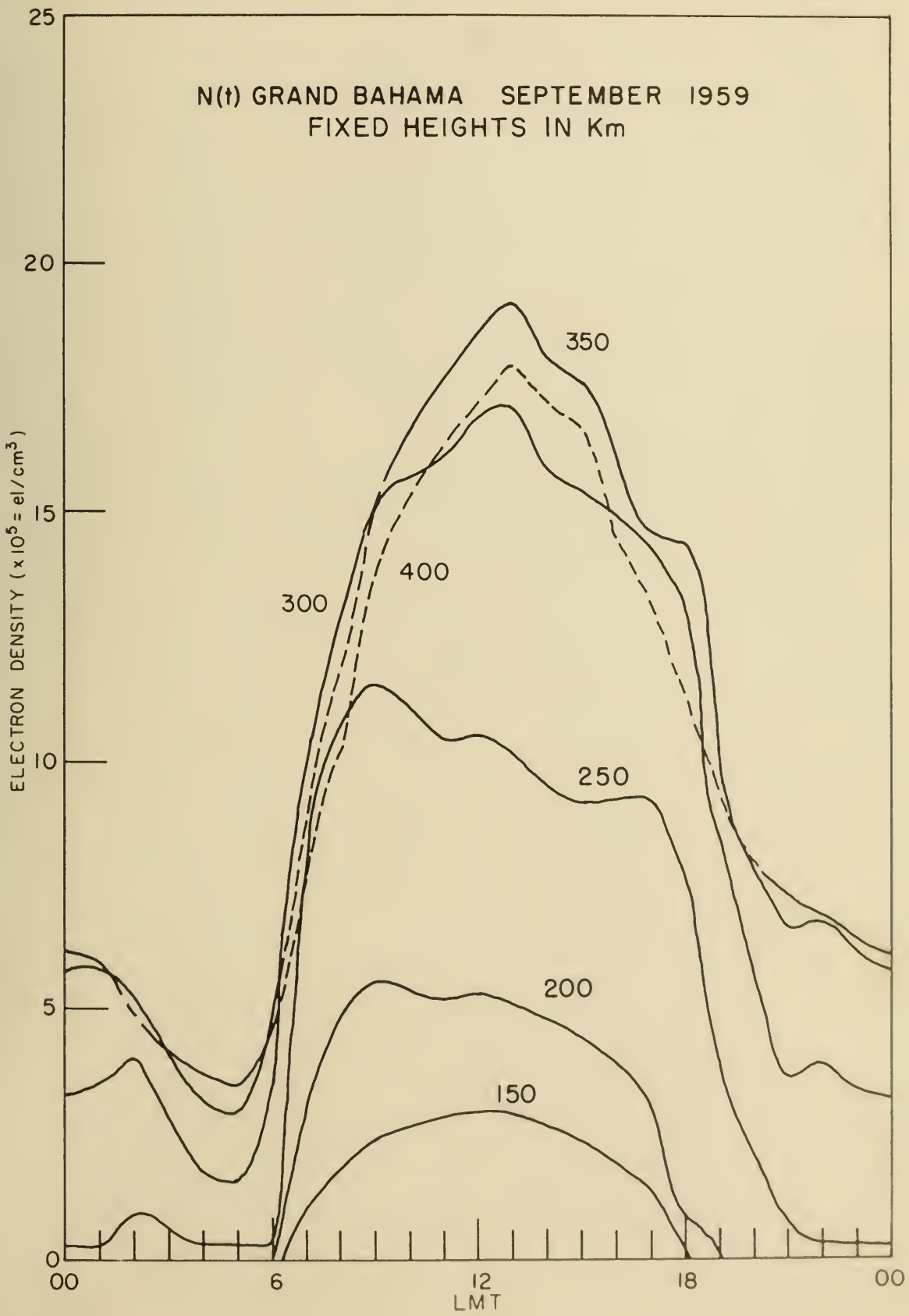
SEPTEMBER 1959

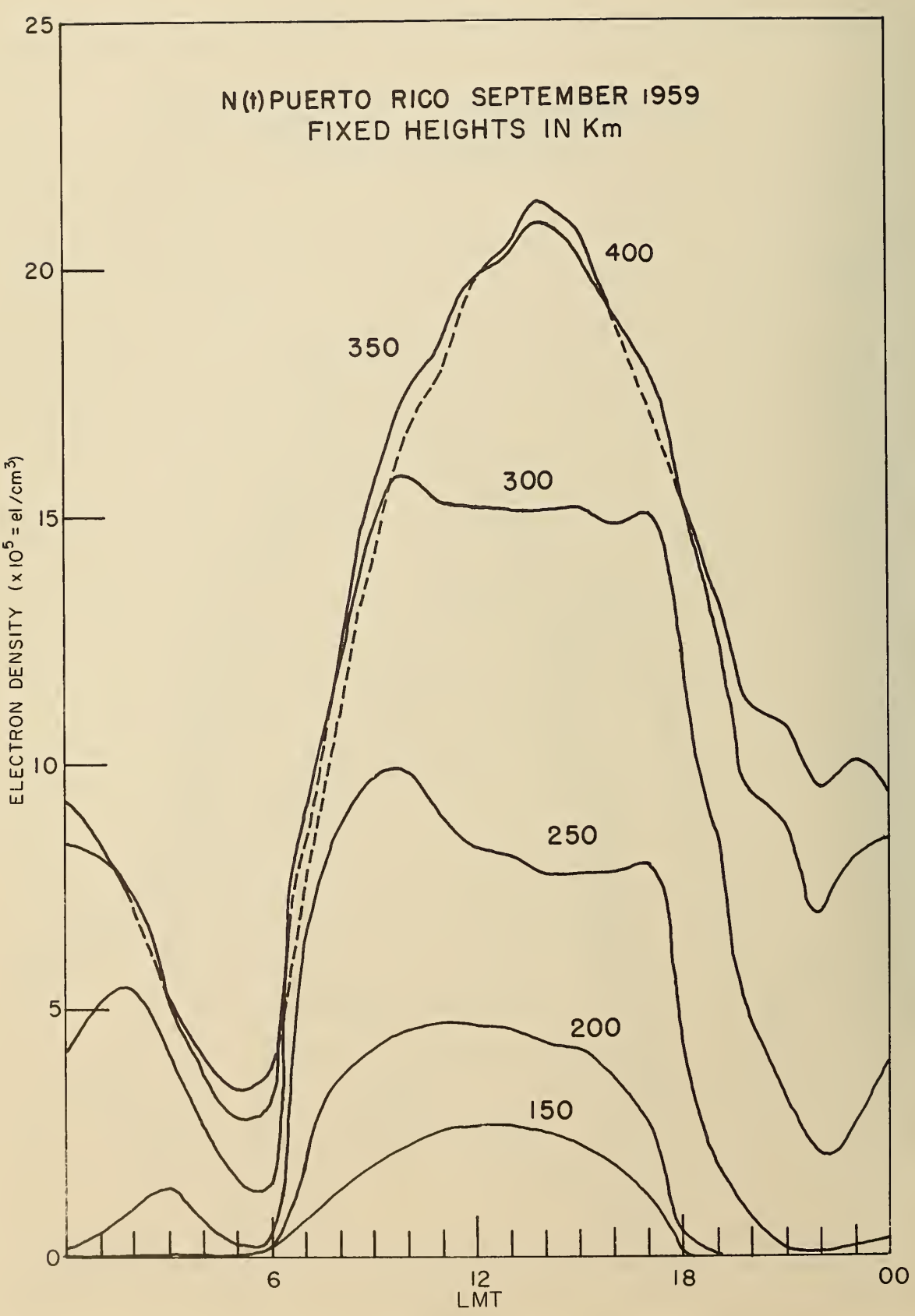



N(t) NEWFOUNDLAND SEPTEMBER 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x 10⁵ = el/cm³)
25
20
15
10
5
0
300
350
250
400
200
150
00
6
12
18
00
LMT


N(t) FT. MONMOUTH SEPTEMBER 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x10⁵=el/cm³)
25
20
15
10
5
0
0
06
12
18
00
LMT
300
350
400
250
200
150


N(t) WHITE SANDS SEPTEMBER 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x10⁵ = el/cm³)
25
20
15
10
5
0
400
300
350
250
200
150
00
6
12
18
00
LMT


N(t) GRAND BAHAMA SEPTEMBER 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x 10^5 = el/cm^3)
25
20
15
10
5
0
350
400
300
250
200
150
00
6
12
18
00
LMT


N(t) PUERTO RICO SEPTEMBER 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x 10⁵ = el/cm³)
25
20
15
10
5
0
400
350
300
250
200
150
6
12
18
00
LMT

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics. High Voltage.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Standard Reference Materials. Applied Analytical Research.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics. Electrolysis and Metal Deposition.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics. Operations Research.

Data Processing Systems. Components and Techniques. Computer Technology. Measurements Automation. Engineering Applications. Systems Analysis.

Atomic Physics. Spectroscopy. Infrared Spectroscopy. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry.

Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Cryogenic Technical Services.

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services. Vertical Sounding Research.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

NBS